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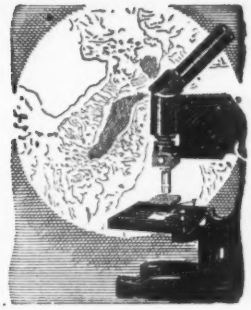

Carbide Precipitation in Tungsten–Chromium Steels below 700° C

By Kehsin Kuo

SYNOPSIS

X-ray and chemical analyses were carried out on carbides extracted electrolytically from steels containing up to 15% W and 12% Cr. All these carbides were derived from the respective carbides in tungsten and chromium steels; M_2C and $M_{23}C_6$ have extended solubility ranges for both tungsten and chromium, M_7C_3 contains mainly chromium in addition to iron, and M_6C mainly tungsten.

The presence of a small amount of chromium reduces the possibility of the appearance of MC, and that of tungsten the appearance of M_7C_3 at equilibrium in tungsten–chromium steels, which usually contain $M_{23}C_6$, M_6C, or both.

Carbide phase-changes are discussed in terms of the compositions of the matrix and the carbides (the atomic ratios W:C, Cr:C, W:Cr). The sequence in which the carbides appear on tempering a steel is M_3C, M_7C_3, $M_{23}C_6$ in high-chromium, and M_3C, M_2C, M_6C, $M_{23}C_6$ in high-tungsten steels. In other steels, combinations of these two sequences, with tungsten and chromium forming separately their own carbides M_6C and M_7C_3, have been observed. 1238

Introduction

A PREVIOUS PAPER[1] reports a study of the carbides existing in chromium, molybdenum, and tungsten steels by means of X-rays, designed to clarify (*a*) which carbides exist at equilibrium with ferrite at 700° C in the respective Fe–*M*–C ternary systems, and (*b*) the carbide reactions taking place towards equilibrium, especially on tempering. It was found that the carbides and their reactions in chromium steels are quite different from those in molybdenum and tungsten steels which give similar results, though these three alloy elements belong to the same group in the Periodic Table. Later, the investigation was extended to complex hot-worked and high-speed steels,[2] containing in general molybdenum or tungsten, or both, as the main alloy elements and chromium as the subsidiary one. Owing to the relatively low content of chromium, the carbide reactions in these steels are rather similar to those found in high-molybdenum or high-tungsten steels. However, chromium seems to retard these reactions on tempering, and this has been considered to be one of the main functions of chromium in these steels.

Besides hot-worked and high-speed steels, a great number of tool steels also contain tungsten and chromium, with the former ranging from 1% to 8% and the latter from 0·5% to 12%. The practical interest of a comprehensive study of the carbides in W–Cr steels is thus very obvious. Since chromium and tungsten form different carbides, such an investigation will also have theoretical interest as an examination of the mutual influences of these two alloy elements in the formation of carbides in the Fe–W–Cr–C quaternary system. The object of this paper is rather to understand the carbides appearing in W–Cr steels than to explain why a certain tool steel requires a special combination of tungsten and chromium to yield certain optimium mechanical properties.

The steels used in the present investigation were either freely available as standard tool steels in Sweden, or specially made in a 25-kg laboratory h.f. furnace, and their compositions are given in Table I. If the designation consists of four numbers, the first two represent the carbon content in 0·1 wt-% and the third and fourth represent respectively the

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Table I

CHEMICAL COMPOSITION OF TUNGSTEN-CHROMIUM STEELS, wt-%

Group	Steel	C	Si	Mn	P	S	Cr	Ni	Mo	W	V	Austenitizing Treatment
I: low atomic ratio W : C	0620	0·55	0·26	0·30	0·008	0·006	0	—	—	1·96	—	1150° C, 30 min
	1351	1·30	0·21	0·35	0·012	0·010	0·60	—	—	5·1	—	1150° C, ,,
	1342	1·28	0·21	0·32	0·022	0·010	1·82	—	—	4·1	0·18	1200° C, ,,
	0521	0·45	0·18	0·37	0·011	0·006	1·44	—	0·30	2·18	0·20	1150° C, ,,
	0323	0·34	0·22	0·25	0·020	0·010	3·25	—	0·18	1·58	0·08	1150° C, ,,
	0315	0·31	0·21	0·34	0·023	0·035	5·0	—	—	1·35	—	1150° C, ,,
	032–12	0·27	0·16	0·27	0·024	0·027	11·6	0·05	—	1·58	—	1200° C, ,,
	030–12	0·30	0·25	0·30	0·022	0·018	12·2	—	—	0	—	1200° C, ,,
II: medium atomic ratio W : C	0351	0·32	0·22	0·32	0·015	0·011	1·15	3·41	—	5·30	—	1200° C, ,,
	0355	0·34	1·20	0·26	0·010	0·008	5·23	—	—	5·42	—	1200° C, ,,
	0359	0·30	0·25	0·33	0·011	0·020	8·72	—	—	5·12	—	1200° C, ,,
	045–13	0·40	0·21	0·20	0·025	0·029	12·6	—	—	5·3	—	1200° C, ,,
III: high atomic ratio W : C	0315–5	0·32	0·18	—	—	0·024	4·61	Traces	0	15·4	0·08	—

tungsten and chromium contents in weight-percent. If it consists of five numbers, the last three are separated by a dash to represent respectively the the tungsten and chromium contents.

The standard methods of investigation are the electrolytic extraction of carbides and their chemical* and X-ray analyses, as described earlier.[1, 4] A point requiring special mention is that the anodic residue of tungsten steels contains, besides carbides, amorphous tungsten oxides formed during the electrolysis in hydrochloric acid. In order to obtain an accurate chemical analysis of carbide, these tungsten oxides have to be removed by treatment with hot 10% NaOH.[4] This has been confirmed by Papier[5] in his carbide analyses of tungsten high-speed steels.

Similar results obtained from Mo–Cr steels are included in the discussion for the purpose of comparison.

SOLID-SOLUTION RANGES OF CARBIDES IN W–Cr STEELS

The previously known carbides of the Fe–W–Cr–C quaternary system are listed in Table II, from which it can be seen that there is no new quaternary carbide; or in other words, all carbides are derived from the respective binary and ternary systems. The characteristics of these carbides, apart from $Cr_{21}W_2C_6$, have been described in earlier papers.[1, 6] According to Westgren *et al.*,[8] the tungsten atoms in $Cr_{21}W_2C_6$ not only substitute for chromium atoms, but also occupy special positions in the carbide lattice. Since the solid-solution ranges of these carbides in certain cases are quite large, as summarized in Table II, the same designation *M* is used for iron, tungsten, and chromium. The carbides $Fe_{20}C_9$ and Cr_3C_2 do not occur in steels, and therefore are not included in the following discussion on the solid-solution ranges of carbides.

* The chemical analysis was carried out at Sandvikens Jernverk under the supervision of Dr. S. Heiskanen, according to the micro-analytical methods described by him.[3]

M_3C (Fe_3C)

According to earlier determinations,[1, 4] cementite can dissolve up to 1·5 wt-% W or 18 wt-% Cr. The alloy content in cementite increases linearly with its content in the steel, the partition ratio between carbide and ferrite being 28, 8, and 2, respectively, for Cr, Mo, and W. This seems to signify a decreasing affinity for carbon with increasing atomic number in the Cr group of elements, as has been suggested elsewhere.[9] However, the atomic size factor may also play an important role in the consideration of solid-solution ranges. In the present case, the smaller partition ratio of W may perhaps be due largely, if not entirely, to its large atomic size.

ϵ-M_2C (ϵ-Fe_3C)

The ϵ-iron carbide has an approximate composition $Fe_{2\cdot4}C$, but its structure is isomorphous with that of other carbides with the general formula

Table II

SOLID-SOLUTION RANGES OF CARBIDES IN THE QUATERNARY SYSTEM Fe–W–Cr–C

Binary and Ternary Systems		Quaternary System Fe–W–Cr–C			
System	Carbide	Carbide Type	Solid-Solution Ranges, wt-%		
			W	Cr	Fe
Fe–C	$Fe_{20}C_9$	*	unknown	unknown	...
Fe–C	Fe_3C	M_3C	0–1	0–18	...
Fe–C	ϵ-Fe_3C	ϵ-M_2C	small	small	...
W–C	W_2C	M_2C	...	0–45	<5
W–C	WC	MC	...	small	small
Fe–W–C	Fe_3W_3C	M_6C	60–70	0–10	25–35
Fe–W–C	$Fe_{21}W_2C_6$	$M_{23}C_6$	0–20	0–95	0–85
Cr–W–C	$Cr_{21}W_2C_6$				
Cr–C	$Cr_{23}C_6$				
Cr–C	Cr_7C_3	M_7C_3	small	...	20–50
Cr–C	Cr_3C_2	*	<20 (7)	...	small

*Not existing in steels

Table III

SOLID-SOLUTION RANGES OF $M_{23}C_6$ FORMED IN TUNGSTEN-CHROMIUM STEELS WITH LOW W : C RATIO

After Isothermal Transformation at 700° C for 25 h

Steel			$M_{23}C_6$							
Designation	Atomic Ratio W : C	Atomic Ratio Cr : C	X-Ray a, Å	Chemical Analysis, wt-%						
				C	Mn	Cr	Mo	W	V	Fe	Total
1351	0·25	0·12	10·52	5·0	1·4	1·9	0·1	17·0	0·5	73·5	99·0
1342	0·21	0·33	10·53	5·4	0·9	6·3	0·1	14·5	0·5	71·5	99·2
0521	0·30	0·74	10·55	5·1	1·0	10·6	3·0	17·1	2·3	57·8	97·2
0323	0·30	2·21	10·59	4·5	0·4	28·1	2·1	20·0	1·1	39·3	95·6
0315	0·28	3·73	10·62	5·4	1·2	42·3	—	12·0	—	33·9	94·8
032–12	0·38	9·92	10·65	4·8	0·5	57·1	—	12·1	—	24·1	98·6

M_2C, e.g. Mo_2C, W_2C, V_2C, etc. Since the ϵ-iron carbide does not exist in steels above 300° C, and since W_2C never forms below this temperature, these two isomorphous carbides can never exist simultaneously. To differentiate between them, the ϵ-iron carbide is denoted here by ϵ-M_2C.

Since this carbide exists only at temperatures much lower than those needed for the diffusion of Cr and W to take place (above 500° C), there can never be any concentration of these elements in this carbide as there may be in cementite formed at high temperatures. During the formation of ϵ-M_2C, only carbon migrates, and this carbide will therefore inherit the alloy proportion of the steel.

M_2C (W_2C)

This carbide forms in high-tungsten steels as a transition carbide in the early stage of tempering.[1, 2] By comparing a series of steels with 0·3% C, 5% W, and different chromium contents, the effect of Cr on the lattice dimensions of M_2C may be used to illustrate qualitatively the solubility of Cr in these carbides. Since the diffraction pattern of M_2C, formed after tempering at 700° C for 6 min, is usually weak and diffuse, the interplanar spacing of the strongest line, (101), is used here for the purpose of comparison:

Pure W_2C	2·27 Å
Steel 0351	2·25 Å
Steel 0355	2·20 Å
Steel 035–9	2·17 Å

This shows that the solubility of Cr in M_2C is substantial.

Ternary W–Cr–C alloys with the common composition M_2C were melted in an argon atmosphere in an arc furnace and then annealed in evacuated silica tubes for 24 h at 1000° C. The M_2C carbide was found to exist alone in alloys with increasing Cr content up to the composition $W_{0·5}Cr_{1·5}C$, above which $M_{23}C_6$ appeared, together with MC. This proves that Cr can replace W in M_2C up to 45 wt-%, in agreement with the findings of Hinnüber and Rüdiger,[10] who found in sintering a mixture of 50 mol-% Cr_3C_2 and 50 mol-% WC that M_2C and graphite were produced:

$$WC + Cr_3C_2 \rightarrow 2W_{0·5}Cr_{1·5}C + C \text{ (graphite)}$$

Ternary W–Fe–C alloys with the common composition M_2C were prepared in the same way, and it was found that iron exists in the free state in all alloys investigated, including $W_{1·7}Fe_{0·3}C$. This means that the solubility of iron in M_2C must be smaller than 5%. Moreover, the lattice dimensions of M_2C extracted from tungsten steels do not differ noticeably from those of pure W_2C,[2] signifying that the solubility of iron in M_2C cannot be large.

The fact that M_2C can dissolve a substantial amount of Cr but very little Fe is quite unexpected, because the isomorphous iron carbide ϵ-M_2C exists whereas Cr_2C does not.

Wever, Krisch, and Wiester[11] recently showed that the Mo_2C carbide in a steel containing 0·04% C, 0·31% Mn, 0·48% Cr, 0·72% Mo, and 1·42% Ni dissolves about 10% Cr, 9% Fe, 7% Mn, and 0·4% Ni by weight. After 221 h tempering at 500° C, the Cr and Mn contents remain nearly the same, but the Fe content drops to about 5%. This indicates not only that the solubility of Cr in M_2C is higher than that of Fe, but also that the M_2C carbide in its early stage of formation may dissolve more iron than at equilibrium. This is possibly because this carbide forms in an iron matrix, and the iron atoms, owing to slow diffusion, are temporarily entrapped in M_2C during its nucleation and growth.

MC (WC)

According to an earlier paper,[1] the lattice constants of MC found in W steels are about the same as those in pure WC, and from this it has been concluded that the solubility of Fe in MC must be very limited. Similar results have been found by Hinnüber and Rüdiger for[10] MC existing in sintered alloys with different proportions of WC and Cr_3C_2, showing that the solubility of Cr in MC cannot be large.

M_6C (Fe_3W_3C)

The chemical analyses of the carbide found in high-speed steels obtained by different authors[5, 12–16] are in good agreement. The M_6C carbide contains about 5–7 wt-% Cr in annealed steels, but only 2–3 wt-% Cr in quenched steels. This indicates that, in the course of heating to 1250–1300° C before quenching, the more weakly bound Cr (and possibly

Table IV

PARTITION RATIO OF MANGANESE, CHROMIUM, AND TUNGSTEN BETWEEN $M_{23}C_6$ AND FERRITE IN STEELS WITH LOW W : C RATIO AND LOW CHROMIUM CONTENT

Steel	Manganese				Chromium				Tungsten			
	Wt Percentage in Steel	Wt Percentage in $M_{23}C_6$	Wt Percentage in α	Partition Ratio	Wt Percentage in Steel	Wt Percentage in $M_{23}C_6$	Wt Percentage in α	Partition Ratio	Wt Percentage in Steel	Wt Percentage in $M_{23}C_6$	Wt Percentage in α	Partition Ratio
1351	0·35	1·0	0·12	8·3	0·6	1·9	0·14	13·6	5·1	17·0	0·92	18·5
1342	0·32	0·9	0·14	6·4	1·8	6·3	0·42	15·0	4·1	14·5	0·87	16·7
0521	0·37	1·4	0·27	5·2	1·44	10·6	0·55	19·3	2·18	17·1	0·74	23·1

also Fe) atoms in the carbide undergo solution preferentially, leaving the carbide enriched in W. According to Kuo,[17] Cr substitutes for Fe but not for W in this carbide.

$M_{23}C_6$($Cr_{23}C_6$, $Cr_{21}W_2C_6$, $Fe_{21}W_2C_6$)

From the carbides $Cr_{23}C_6$, $Cr_{21}W_2C_6$, and $Fe_{21}W_2C_6$ existing in the respective binary and ternary systems, it is to be expected that the W and Cr contents in the $M_{23}C_6$ carbide in the Fe–Cr–W–C quaternary system may vary considerably. A series of W–Cr steels was chosen with an atomic ratio W : C of about 0·2–0·4, so that the carbide obtained after isothermal transformation for 25 h at 700° C is always the $M_{23}C_6$ carbide. The reason for choosing this atomic ratio and heat-treatment has been mentioned earlier[1] and will be further discussed later in the present paper.

From Table III it can be seen that as the atomic ratio Cr : C in the steel increases, the Cr content of the $M_{23}C_6$ carbide increases from 1·9 to 57·1 wt-%. The increase seems to occur linearly at small Cr : C ratios (0·12–0·74) but becomes smaller as this atomic ratio becomes larger. The tungsten content is fairly constant, though this also seems to decrease with increase in the atomic ratio of Cr : C. Earlier, Popova and Platonova[18] found a similar concentration of tungsten in $M_{23}C_6$ in a W–Cr steel.

There also seems to be a concentration of Mn in the $M_{23}C_6$ carbide, 0·4–1·4 wt-% in comparison with 0·2–0·4 wt-% in the steels. A similar concentration of manganese in $M_{23}C_6$ has been observed by Heiskanen[19] in a Cr–Mn steel with 0·18% C, 12·7% Cr, and 0·34% Mn. This is not unexpected, since Mn also forms a carbide with the formula $Mn_{23}C_6$.[20]

The partition ratios for Mn, Cr, and W between $M_{23}C_6$ and ferrite have been calculated for steels with low alloy contents, because this kind of distribution is considered to be a constant only in dilute solid solutions. The carbon balance was used to calculate the respective amounts of carbide and ferrite, and the alloy balance to calculate the alloy content of ferrite. The results are shown in Table IV. The agreement of the results is not good, but it indicates that the partition ratios for Cr and W are about the same and that for Mn is smaller.

This sort of concentration of Mo, Cr, and Mn in $M_{23}C_6$ has also been found in a tool steel with 0·95% C, 1·05% Mo, 5·12% Cr, and 0·52% Mn. After austenitizing at 1200° C and isothermal transformation at 700° C, this steel contains only the $M_{23}C_6$ carbide, whose analysis is 5·7% C, 2·2% Mn, 26·8% Cr, 4·0% Mo (by weight).

M_7C_3 (Cr_7C_3)

The solubility of W in M_7C_3 has not been determined, mainly because a small addition of W to Cr steels causes the appearance of $M_{23}C_6$ together with M_7C_3, so that direct chemical analysis of this carbide cannot be obtained. A steel with 2·05% C and 11·2% Cr contains in the annealed state only M_7C_3, but the addition of about 1% W to this steel leads to the appearance of $M_{23}C_6$ as well. This indicates that most of the added W is concentrated in the small amount of $M_{23}C_6$ carbide, and that the amount of W that could be dissolved in M_7C_3 must be very small.

Among the carbides mentioned above, M_2C and $M_{23}C_6$ have extended solubility ranges for both W and Cr, M_7C_3 is mainly a Cr-containing and MC and M_6C are mainly W-containing carbides.

CARBIDE REACTIONS ON TEMPERING OF W–Cr STEELS

In the study of the carbides in alloy steels[1] it has been found that the occurrence of a certain alloy carbide is governed not only by the alloy content but also by the carbon content of the steel. Therefore, the idea of using the atomic ratio of metal to carbon M : C has been introduced. As this ratio increases, the equilibrium carbide appears in the order Fe_3C, Cr_7C_3, $Cr_{23}C_6$ in chromium and in the order Fe_3C, $M_{23}C_6$, M_6C in tungsten steels.

Low-chromium Steels

The addition of a small amount of chromium does not change the carbide reactions in tungsten steels, though it may delay the precipitation of the MC carbide. The deterioration of tungsten magnetic steel with about 0·6%C and 6% W is supposed to be due to the precipitation of MC. Zieler[21] showed that the presence of 0·35% Cr in this magnetic steel lessens the rate of deterioration resulting from annealing. This delaying action can also be seen in Table V. The presence of 0·7% Cr in steel 1351 greatly retards the formation of MC which appears only after 500 h tempering at 700° C, and that of 1·82% Cr in steel 1342 completely eliminates the occurrence of this carbide.

However, if the steel 1351 is heated to 850–1000° C,

Table V

CARBIDE REACTIONS OCCURRING IN TUNGSTEN–CHROMIUM STEELS WITH LOW TUNGSTEN : CARBON ATOMIC RATIOS (0·2–0·3)

Steel			X-ray Analysis of Carbides after Tempering at 700° C for					
Designation	Atomic Ratio W : C	Atomic Ratio Cr : C	6 min	1 h	5 h	25 h	125 h	500 h
0620	0·23	0	M_3C	M_3C+M_6C	M_3C+M_6C+MC	M_3C+MC	M_3C+MC	M_3C+MC
1351	0·25	0·12	M_3C	M_3C	$M_3C+M_{23}C_6+MC$	$M_{23}C_6+M_6C+MC$	$M_{23}C_6+M_6C$	$M_{23}C_6+MC$
1342	0·21	0·33	M_3C	M_3C	$M_6C+M_{23}C_6+MC$	$M_{23}C_6+M_6C+MC$	$M_{23}C_6+M_6C$	$M_{23}C_6$
0521	0·30	0·74	M_3C	M_3C	M_3C+M_6C	M_3C+M_6C	M_3C+M_6C	$M_3C+M_6C+M_{23}C_6$
0323	0·30	2·21	M_3C	M_7C_3	$M_7C_3+M_6C$	$M_7C_3+M_6C$	$M_7C_3+M_6C$	$M_7C_3+M_6C+M_{23}C_6$
0315	0·28	3·73	M_7C_3	M_7C_3	$M_7C_3+M_{23}C_6$	$M_{23}C_6+M_7C_3$	$M_{23}C_6$	$M_{23}C_6$
032–12	0·38	9·92	M_7C_3	$M_{23}C_6$	$M_{23}C_6$	$M_{23}C_6$	$M_{23}C_6$	$M_{23}C_6$
030–12	0	9·4	M_7C_3	$M_{23}C_6$	$M_{23}C_6$	$M_{23}C_6$	$M_{23}C_6$	$M_{23}C_6$

MC appears very rapidly and a large amount of angular MC carbides forms within 1 h. Since this steel is usually forged within this temperature interval, the formation of some MC in this steel can never be avoided. Even this heat-treatment fails to produce MC in the steel with a higher chromium content (steel 1342).

Steels with Low W : C Ratio

This series of steels has a W : C atomic ratio of 0·2–0·4, so that the stable carbide is $M_{23}C_6$ (*see* Table III), and a Cr : C atomic ratio varying from 0·7 to 10, so that the effect of chromium on the carbide reaction can be studied. This is of special theoretical interest because in these steels the carbides existing at the start and completion of the tempering, M_3C and $M_{23}C_6$ respectively, are the same, but the carbide reactions occurring between these two stages are quite different as the result of the different chromium contents, as shown in Table V. For the sake of comparison, the carbide reactions in a tungsten (steel 0620) and a chromium (steel 030–12) steel studied earlier[1] are also included in this table.

(i) *Steels* 1351 *and* 1342—The carbide reactions in these two steels are very alike, and are also similar to that occurring in a tungsten steel with similar W : C ratio (steel 0620). On tempering, M_3C appears first, and as the W : C ratio of the matrix, owing to the reduction in carbon content, increases considerably, the tungsten-containing carbide M_6C follows first and $M_{23}C_6$ later. On prolonged tempering, M_3C and M_6C redissolve to form more $M_{23}C_6$. During these carbide phase-changes, chromium is dissolved, at first mostly in M_3C and later in $M_{23}C_6$, and tungsten at first mostly in M_6C and later in $M_{23}C_6$ or MC. The effect of chromium in prohibiting the formation of MC is obvious, and has been discussed earlier.

(ii) *Steel* 0521—The carbide reaction in this steel is similar to that discussed above, except that the appearance of $M_{23}C_6$ is greatly retarded. This cannot be due to the higher Cr : C ratio, which should promote the formation of $M_{23}C_6$. Comparing this steel with steels 1351 and 1342, it will be seen that, although the W : C ratios are about the same, the tungsten content and therefore the W : C ratio of ferrite after the formation of M_3C in this steel, are smaller. After the formation of M_6C, the ferrite does not have enough tungsten (and chromium, which is mostly dissolved in M_3C) to form immediately the $M_{23}C_6$ carbide, and only after long tempering do chromium and tungsten co-operate to form this carbide. This illustrates well the fact that, in dealing with carbide reactions, not only the M : C ratio but also the alloy content should be taken into consideration.

(iii) *Steel* 0323—Owing to the high content of chromium, M_7C_3 appears to replace M_3C and coexists with M_6C. This shows that, on tempering, chromium and tungsten atoms fail to co-operate to form together immediately the $M_{23}C_6$ carbide, but instead form their own carbides, M_7C_3 and M_6C respectively.

The appearance of M_7C_3 as an intermediate carbide does not seem to be affected by the presence of tungsten, since if tungsten is absent this carbide still appears in this steel, but not in steel 0521. Similarly, a small amount of chromium does not seem to have any significant influence upon the appearance of M_6C.

In a Mo–Cr steel with 0·11% C, 1·02% Mo, and 2·10% Cr, the carbide reaction on tempering is $M_3C \rightarrow M_7C_3 + M_3C \rightarrow M_7C_3 + M_2C + M_6C \rightarrow M_7C_3 + M_6C$. In this case M_2C appears before M_6C as an intermediate carbide, and $M_{23}C_6$ fails to appear, even after 500 h at 700° C.

(iv) *Steels* 0315 *and* 032–12—The carbide sequence in these two steels is $M_3C \rightarrow M_7C_3 \rightarrow M_{23}C_6$, the same as that found in high-chromium steels. The early appearance of $M_{23}C_6$ absorbs, besides chromium, a large amount of tungsten, thus eliminating the possibility of the appearance of M_6C intermediately.

Note that, if tungsten were absent, steel 0315 would contain only M_7C_3, so that the appearance of $M_{23}C_6$ in this steel is the result of co-operation of chromium and tungsten. However, this is not the case with steel 032–12, which contains enough chromium to form $M_{23}C_6$, whether tungsten is present or not.

All these steels contain only $M_{23}C_6$ at equilibrium, and this can easily be attained by isothermal transformation at 700° C. Since the approach to equilibrium in certain steels is extremely reluctant, the possibility of the formation of any other carbide preceding $M_{23}C_6$ during this isothermal transformation can therefore be excluded. In other words, chromium and tungsten atoms, together with iron and carbon atoms, which are readily available as a

Table VI

CARBIDE REACTIONS OCCURRING IN TUNGSTEN–CHROMIUM STEELS WITH 0·3–0·4% AND 5% W

Steel			X-ray Analysis of Carbides after Tempering at 700° C for				
Designation	Atomic Ratio W : C	Atomic Ratio W : Cr	6 min	1 h	5 h	25 h	125 h
0351	1·1	1 : 0·8	M_2C	M_6C	M_6C	M_6C	$M_6C+M_{23}C_6$
0355	1·0	1 : 3·4	M_2C	$M_6C+M_7C_3$	$M_6C+M_7C_3$	$M_6C+M_7C_3$	$M_6C+M_{23}C_6+M_7C_3$
0359	1·1	1 : 6·0	$M_{23}C_6+M_2C$	$M_{23}C_6$	$M_{23}C_6+M_6C$	$M_{23}C_6+M_6C$	$M_{23}C_6+M_6C$
045–13	0·87	1 : 8·4	$M_{23}C_6+M_2C$	$M_{23}C_6$	$M_{23}C_6$	$M_{23}C_6$	$M_{23}C_6$

result of either abundance or high diffusion rate, co-operate during the isothermal transformation to form this carbide. This is possibly because these alloy atoms possess sufficiently high mobility at the isothermal transformation temperature, and because the matrix has a suitable composition, especially as regards the M : C ratio, to form this carbide. This means that, under favourable temperature and composition conditions, chromium and tungsten do co-operate to form a common carbide. Another example of this kind of co-operation will be given later in the paper.

To summarize, it could be said that, on tempering W–Cr steels with low W : C ratios, equilibrium can be attained easily only in high-chromium and medium-tungsten steels, and in other steels chromium and tungsten tend to form separately their own carbides (MC_7C_3 and M_6C).

Medium-tungsten Steels

Four steels with about 0·3–0·4% C, 5% W, and different chromium contents were examined (Table VI). The atomic ratio W : C in these steels is about 1·0, which enables M_2C to appear immediately after M_3C on tempering at 700° C. The effect of chromium on the lattice dimensions of M_2C in these steels has been discussed earlier in connection with the solid-solution ranges of this carbide. Since M_2C can dissolve as much as 45 wt-% Cr, the formation of this carbide in W–Cr steels can be considered as the result of co-operation of tungsten and chromium atoms, even though the presence of chromium is not a necessary condition for its formation.

The carbide appearing after M_2C differs as the chromium content varies; this will be discussed separately below:

(i) *Steel* 0351—The tungsten-containing carbide M_6C appears immediately after M_2C, and the carbide reaction in this steel is similar to that found in a tungsten steel with 0·27% C and 5·45% W,[1] namely, $M_3C \rightarrow M_2C \rightarrow M_6C \rightarrow M_6C + M_{23}C_6$. This shows that the presence of 1% Cr in tungsten steels does not change the carbide reactions, though it seems to delay these phase changes.[2] The small amount of chromium is believed to be dissolved either in the matrix or in one of the following carbides: M_3C, M_2C, and $M_{23}C_6$.

(ii) *Steel* 0355—In the steel containing 5% Cr, the disappearance of M_2C, owing to its high chromium content, produces not only the tungsten-containing carbide M_6C but also the chromium carbide M_7C_3. These two carbides coexist for a long period until some $M_{23}C_6$ appears after tempering at 700° C for 125 h. At equilibrium, as found by isothermal transformation at 700° C, the M_7C_3 carbide is not present, and chromium is mostly dissolved in $M_{23}C_6$, and tungsten largely in M_6C and some in $M_{23}C_6$.

It is of interest to compare the carbide reactions in steels 0315 (Table V) and 0355 (Table VI), because this will show the effect of different tungsten contents on the carbide reactions in 5% Cr steels. In steel 0315, M_7C_3 appears already after 6 min and $M_{23}C_6$ after 5 h at 700° C. In steel 0355, M_7C_3 appears (after M_2C) first after 1 h and $M_{23}C_6$ after 125 h at 700° C. This implies that tungsten delays the appearance of M_7C_3 through the formation of M_2C, which absorbs chromium and reduces the chromium content of ferrite. The late appearance of $M_{23}C_6$ is possibly due to the delayed formation of M_7C_3 and to the formation of M_6C, which absorbs a great deal of tungsten.

In this steel tungsten and chromium atoms co-operate first to form M_2C, but fail to do so in forming $M_{23}C_6$ immediately after M_2C. This is perhaps because M_2C can tolerate a large change in chromium and tungsten proportions while $M_{23}C_6$ (at the ideal composition $Cr_{21}W_2C_6$) could dissolve only 1 tungsten atom to 10·5 chromium atoms. This steel has an atomic ratio W : Cr of 1 : 3·4, which, together with the high W : C atomic ratio, favours the formation of M_6C.

(iii) *Steel* 0359—As the chromium content reaches 9%, $M_{23}C_6$ appears, together with M_2C, after tempering at 700° C for 6 min. Up to now it has not been possible to ascertain whether the appearance of $M_{23}C_6$ is preceded by M_7C_3 or only by M_2C. If the carbide sequence is: M_2C, $M_{23}C_6$, $M_{23}C_6 + M_6C$, then it perhaps can be assumed that $M_{23}C_6$ forms directly from the matrix resulting from the co-operation of tungsten and chromium. This is not at all impossible, since the W : Cr atomic ratio in this steel is about 1 : 6·5, not far from that of $Cr_{21}W_2C_6$. Another possibility is that carbides M_2C and M_7C_3 form together after M_3C, and later $M_{23}C_6$ appears after M_7C_3, as it does in high-chromium steels. This means that, notwithstanding the fact that

part of the chromium is dissolved in M_2C, the matrix still has a fairly high chromium content, enabling M_7C_3 to appear.

Since the W : Cr atomic ratio in this steel (1 : 6·0) is larger than that of $Cr_{21}W_2C_6$ (1 : 10·5), after the formation of $M_{23}C_6$ there will be tungsten in excess. Therefore, the tungsten-containing carbide M_6C appears later on.

(iv) *Steel* 045–13—The carbide reaction in this steel is similar to that in steel 0359, except that M_6C never appears. Since this steel has a W : Cr atomic ratio (1 : 8·4) close to that of $Cr_{21}W_2C_6$, this is not unexpected.

High-tungsten Steels

The carbide reactions in high-tungsten W–Cr steels have already been studied and published.[2] Hot-worked steels contain about 9% W and 3% Cr, and high-speed steels about 15–20% W and 4% Cr. These steels show the typical carbide reaction in high-tungsten steels: $M_3C \rightarrow M_2C \rightarrow M_6C$. When the W : C ratio is smaller than 3, there is the possibility of the appearance of $M_{23}C_6$ together with M_6C. The chromium-containing carbide M_7C_3 does not seem to appear.

Steel 0315–5 contains, after annealing at 700° C for 100 h, only ferrite and M_6C, and the composition of the latter is 1·8% C, 4·8% Cr, 65·0% W, 20·4% Fe. This confirms that M_6C dissolves only about 5% Cr and that neither $M_{23}C_6$ nor the chromium-containing carbide M_7C_3 appears when the W : C ratio is above 3. In other words, most chromium remains in the matrix.

This steel has a W : Cr ratio nearly equal to unity, but the carbide is dominated by tungsten. This implies that tungsten is more important than chromium in determining both the equilibrium carbide and carbide phase-changes in W–Cr steels. However, by increasing the chromium content, M_7C_3 may occur in the carbide reaction and $M_{23}C_6$ in the final state.

Carbides in W–Cr Steels

From the above discussion it is clear that the presence of a small amount of tungsten will cause the appearance of $M_{23}C_6$, which contains besides tungsten a substantial quantity of chromium, thus reducing the possibility of the formation of M_7C_3. The latter carbide may appear as an intermediate carbide but seldom exists at equilibrium.

The carbides most frequently encountered in W–Cr steels are $M_{23}C_6$ and M_6C. The former appears often in steels with small W : C ratio or high chromium content, and the latter in steels with medium or high W : C ratio.

The MC carbide commonly does not occur in steels containing 1% Cr or more; and M_2C appears only in high-tungsten steels as an intermediate phase during tempering, whether chromium is present or not.

CONCLUSIONS

(1) There is no new carbide in the quaternary system Fe–W–Cr–C, and all carbides present in W–Cr steels are derived from the respective carbides in tungsten and chromium steels.

(2) The M_2C carbide may dissolve up to 45% Cr and 97% W, and $M_{23}C_6$ up to 65% Cr and 20% W, but M_7C_3 contains, besides iron, mostly chromium, and M_6C mostly tungsten.

(3) Chromium delays the formation of MC and promotes that of $M_{23}C_6$ in W–Cr steels.

(4) The presence of a small amount of tungsten causes the appearance of $M_{23}C_6$, which absorbs a substantial amount of chromium, thus reducing the possibility of the existence of M_7C_3 at equilibrium.

(5) At equilibrium $M_{23}C_6$ exists in steels with small W : C ratio or high chromium content, and M_6C in steels with medium or high W : C ratio.

(6) The carbide sequence occurring on tempering is M_3C, M_7C_3, $M_{23}C_6$ in high-chromium, and M_3C, M_2C, M_6C, $M_{23}C_6$ in high-tungsten steels. Various combinations of these two sequences have been observed in other steels, in which tungsten and chromium form separately their own carbides, M_6C and M_7C_3, respectively, as intermediate phases.

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Co-operative Trials on All-Basic Furnace Roofs

By the All-Basic Furnace Sub-Committee of B.I.S.R.A. and B.Ceram.R.A.

SYNOPSIS

All-basic open-hearth roof trials at four steelplants are described. Seven of the eleven trials were panel roofs of either Detrick or Continental suspension. The panel roofs were built with either four or five transverse panels of two or three brick brands so that at least two brands of bricks of different chemical and physical properties could be compared under the same conditions in one roof. A comprehensive list of laboratory properties had been compiled and the test results obtained from users, makers, and the Research Associations are reported on unused brick samples taken from each of the brick consignments. The conditions of the roofs at the end of the campaigns are described and the results of the laboratory examination of used brick samples are discussed. Furnace design and operation appear to dominate the behaviour of the bricks in service but it is suggested that volume stability at 1700° C, high resistance to thermal shock, and high refractoriness-under-load also contribute to long campaign life. 1379

Section 1—Introduction

IN 1947 the All-Basic Furnace Sub-Committee of the British Ceramic Research Association and the British Iron and Steel Research Association issued two memoranda[1] which gave recommendations for the design and construction of all-basic furnaces. These reports were followed in 1952 by Special Report No. 46 of The Iron and Steel Institute[2] on " The All-Basic Open-Hearth Furnace," which was a report of the 36th Steelmaking Conference and was also prepared by the All-Basic Furnace Sub-Committee. Following the publication of this special report, a further conference was held in 1952 in Scotland and the proceedings were published by the West of Scotland Iron and Steel Institute.[3]

The present paper gives details of the further trials arranged by the All-Basic Furnace Sub-Committee since 1952.

A section of the Special Report No. 46 describes the performance of the basic bricks in six trial furnaces. The pattern of wear was usually very similar to that in silica roofs, but the deterioration of the basic brick was by peeling, slabbing away, or shelling (hereafter referred to as ' slabbing ') of pieces about 1–1½ in. thick; a typical example is shown in Fig. 1. At this time it was considered that such slabbing may be caused by iron oxide pickup and bursting expansion, migration of fluxes, or mechanical properties. It was generally considered that fired bricks were more satisfactory than unfired bricks and that desired properties were high refractoriness-under-load, low bursting expansion, and high thermal shock resistance. A critical analysis of these furnace trials was made and it was considered important that the roof temperature should not fall below 1200° C; further, that fast driving rates and higher temperatures should be attained with the all-basic furnace but that the greatest chance of improved performance lay in the development of an improved and, if possible, cheaper brick.

At the 1952 conference, it was considered that it was not known precisely what was required in the basic brick and that a compromise of all the main laboratory properties had been sought, with the result that some properties may have been over-emphasized and others, which may be the real controlling factors, had therefore been poorer than they need have been.

With this background knowledge and experience, the Sub-Committee decided to embark on a further series of trials, the object of which was to try to correlate the behaviour of basic bricks in service with their properties as determined in the laboratory and to determine the significant laboratory properties.

The present trials were essentially trials of basic bricks in roofs. The performance of bricks in other parts of the furnace was not a major consideration.

The bricks used in all the trial furnaces were made by four U.K. and two Austrian manufacturers. Only fired products were used but these included both chrome-magnesite (" C/M ") and magnesite-chrome (" M/C "). Natural and sea-water magnesites were used in their manufacture, and in the choice of chrome ore both chemical and physical properties were taken into account. In previous trials the choice of chrome ore had been based on its chemical composition, particularly the iron oxide content, because of its effect on bursting expansion and oxidation-reduction expansion. Research work,[4,5] however, has shown that the physical nature of the chrome grains also has an important bearing on the iron oxide bursting expansion.

Since operating conditions vary from furnace to furnace at one plant, and much more from plant to plant, and since, also, panel roof trials had proved very useful in Holland, it was decided to try to compare bricks of different properties and compositions in panelled roofs. It was not always practicable to make all the trial roofs with more than one type of brick but seven of the eleven trial roofs were panelled. The eleven all-basic furnace campaigns took place under normal operating conditions at four steel

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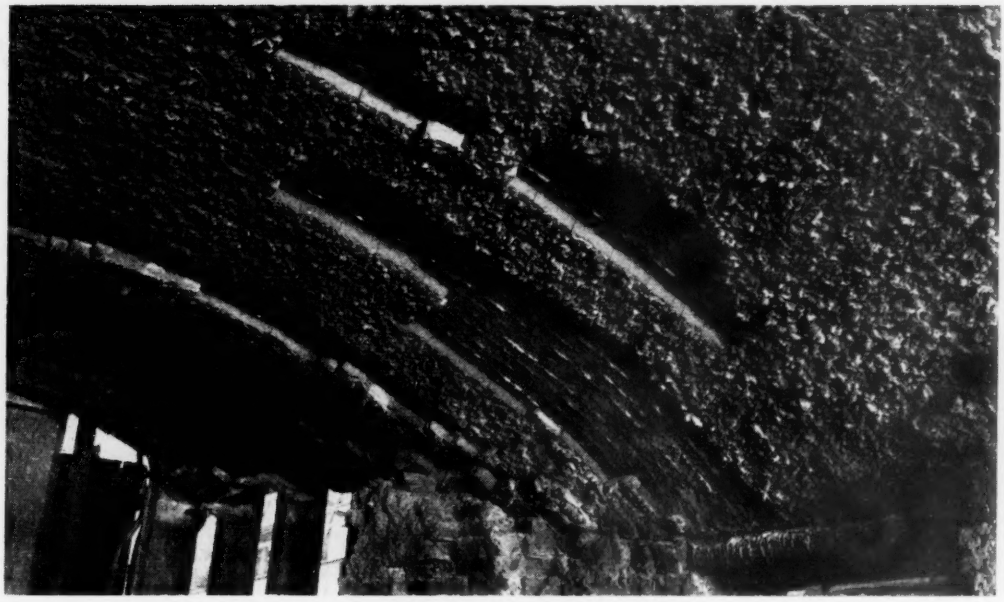


Fig. 1—Severe slabbing of a basic roof

plants: Stewarts and Lloyds Ltd., Bilston; The Consett Iron Co. Ltd.; The United Steel Cos., Ltd., Steel, Peech and Tozer; and the Koninklijke Nederlandsche Hoogovens en Staalfabrieken, N.V., Ijmuiden, Holland (referred to in the paper as 'Bilston,' 'Consett,' 'Steel, Peech and Tozer,' and 'Ijmuiden').

The work entailed testing at least 20 batches of basic bricks in the laboratory and a complete series of laboratory tests was drawn up for the purpose. For most bricks test results were obtained from the manufacturer, from the user, and from the B. Ceram. R.A. These results were carefully compared by representatives from the various laboratories and any discrepancies were investigated.

It was also necessary to study the behaviour of the roofs during service. This was done by the steelworks staff, but the progress was reported to the Sub-Committee and members visited various furnaces at shut-down and other times. At the end of the campaign the roof was inspected not only by the steelworks staff but also by the brick manufacturer and by representatives of the Research Associations. The roof thickness was carefully measured and used brick samples were taken for laboratory examination.

The results have been considered at a number of Committee meetings and members' views and theories on the many problems encountered have been taken into account, so that the paper attempts to give the results and the findings of the Sub-Committee as a whole.

Section 2—TRIAL FURNACES AND ARRANGEMENT OF BRICKS IN ROOFS

Basic roof panel trials had already been run at Ijmuiden, where five panels had been constructed across the roof from the front to the back wall, one panel opposite each of the five doors. Three brands of brick had been used in the five panels which were arranged in the order *X.Y.Z.X.Y*. The centre panel *Z* was built with a standard brick of known high quality because the position of worst wear always occurred in the centre of the roof. In this type of trial, brick *X* is compared with brick *Y*, and it is possible to compare the end panel *X* with the opposite end panel *Y*, and also panels *Y* and *X* that are adjacent to panel *Z* are compared, but the relative merit of *Z* with *X* and *Y* is only a secondary consideration.

Two trial roofs of this construction were studied at Ijmuiden and the two roofs at Consett followed the same pattern. At Bilston, the behaviour of a complete roof made of one brand of brick was followed but at the Templeborough melting shop of Steel, Peech and Tozer, three of the six trials were essentially complete roofs and the other three were panel roofs containing only four panels arranged in the order *X.Y.X.Y*. A fifth central panel was not needed because the positions of worst wear on the roofs at this melting shop usually occurred above the back and above the front walls along the length of the furnace.

This arrangement of the panels in the eleven furnaces and the numbers and colours consigned to the various brick batches are shown diagrammatically in Fig. 2. The letters *A* to *F* refer to the six brick manufacturers. Details of furnace operation and performance are shown in Tables I–III.

TRIAL FURNACES AT STEEL, PEECH AND TOZER

'F' Furnace

1st Campaign

This cold-charged furnace had been rebuilt as a 100-ton furnace but, whilst awaiting enlarged crane capacity, tapped only 80 tons in this campaign.

Table I

OPERATION AND PERFORMANCE DETAILS OF THE TRIAL FURNACES AT STEEL, PEECH AND TOZER

Furnace	'F'			'B'		
Type	Fixed 100% cold-metal (60% scrap, 40% pig)			Fixed 100% cold-metal (60% scrap, 40% pig)		
Roof span	18 ft 7 in.			18 ft 3½ in.		
Roof length between burner tips	54 ft			46 ft 6 in. (bridge walls)		
Campaign	1st	2nd	3rd	7th	8th	9th
Tapping capacity, tons	80	80–100	100	80–100	100	100
Casts per full week	17·9	16·5	14·1	15·2	14·5	13·6
Tap-to-tap output, tons/h	8·79	8·69	8·56	8·05	8·69	8·25
Av. tap-to-tap time, h	9·38	10·12	11·92	10·88	11·63	12·22
Av. fettling time, h	1·22	1·30	1·28	1·23	1·32	Not known
Fuel burnt	Oil	Oil	Oil	Oil	Oil	Oil
Fuel consumption, gal/ton	34·3	33·1	36·1	35·4	33·3	35·8
Fuel consumption, therms/ton	61·0	58·9	64·2	63·0	59·2	63·7

The complete roof, built with the brown chrome-magnesite brick No. 1C, consisted of suspended rib brick 16½ in. long, each rib consisting of two courses, and three courses of intermediate bricks (12 in. long and $6\frac{17}{32}$–$6\frac{1}{8}$ in. × $2\frac{61}{64}$–$2\frac{3}{4}$ in. cross-section) wedged between the tapered ribs, with steel plates between each brick face. The roof span was 18 ft 7 in. and its length was 54 ft between burner tips. The roof was of special construction in that the water-cooled skewback channels were firmly fixed to a lever system which, by means of weights, would automatically compensate the roof movements and relieve high stresses in the refractories.

The single-uptake, oil-fired, single-burner furnace had been built with enlarged flues, archless door frames, and solid end and chill walls. It was designed for a maximum input of 350 gal/h and was expected to operate at a maximum roof temperature of 1680° C.

2nd Campaign

In the second campaign the roof was built with the brown chrome-magnesite brick No. 3C; the conventional Continental spring-loaded skewback was used. The brick dimensions were the same as in the first campaign but there were no steel sheets in the transverse joints. It was necessary to build a 6-ft wide panel of the blue brick No. 4A across the centre of the roof because of a shortage of brown bricks. The furnace began to work as a 100-ton furnace after tapping 152 casts of 80 tons.

3rd Campaign

The third campaign was run with a panelled roof of blue and yellow bricks Nos. 4A and 6A, respectively. The blue brick was chrome-magnesite, but the yellow was a magnesite-chrome brick made by the same manufacturer. The suspended ribs were again two courses of 16½-in. bricks and three courses of 12-in. intermediate bricks were wedged between the ribs as in the first campaign. The width of the end panels of blue and yellow bricks were each one-third of the length of the main roof and were carried on independent skewback channels. The inner two panels were each one-sixth of the length of the main roof and were carried on a third skewback channel. The junction of the two inner panels was over the centre-line of the middle door and the taphole, and the left-hand and right-hand charging doors corresponded with the centre-line of their respective panels. The roof construction was the conventional Austrian suspended type with spring-loaded skewbacks.

Table II

OPERATION AND PERFORMANCE DETAILS OF THE TRIAL FURNACE AT CONSETT

Furnace	'J'					
Type	Fixed: 160 tons tapping capacity. Both hot and blown metal charged.					
Roof span	19-ft Roof rise was 1·33 in. per ft of chord					
Roof length between burner tips, ft	57					
Campaign	4th			5th		
Casts per full week	15·8			15·7		
Steel process and number of casts	M.S. (71)	S.D. (38)	D. (104)	M.S. (17)	S.D. (104)	D. (130)
Tap-to-tap output, tons/h	13·1	13·9	17·9	11·25	12·9	19·6
Av. tap-to-tap time, h	12·5	11·45	9·04	13·6	12·3	8·1
Av. fettling time, h	1·21	1·84	1·81	1·4	2·0	1·7
Fuel burnt	54% tar, 46% coke-oven gas			54% tar, 46% coke-oven gas		
Fuel consumption, therms/ton	47			47		

Note: M.S. = Maximum scrap, i.e. 75–80% scrap, 20–25% hot metal.
S.D. = Semiduplex, i.e. 50% scrap, 25–30% hot metal, 25–30% blown metal.
D. = Duplex, i.e. 5% scrap, 20–25% hot metal, 70–75% blown metal.

Table III

OPERATION AND PERFORMANCE DETAILS OF THE TRIAL FURNACES AT IJMUIDEN AND BILSTON

Firm	Bilston	Ijmuiden	
Furnace	'A'	No. 4	No. 3
Type	Tilting 60-ton: 38% hot metal	Fixed 190-ton: 35% hot metal, 3% pig	
Roof span, ft	17	22	
Roof length between burner tips	57 ft 4 in.	46 ft	
Campaign	4th	1st	2nd
Casts per week	19·9	14·2	16·6
Tap-to-tap output, tons/h	6·5	16·7 (metric)	18·36 (metric)
Av. tap-to-tap time, h	8·4	11·3	10·2
Av. fettling time, h	1·7*	0·55	0·57
Fuel burnt	Oil	Oil	Oil
Fuel consumption:			
Cal/ingot m. ton	..	$1·11 \times 10^6$	$0·97 \times 10^6$
Therms/ton	..	44·6	39·1

*It should be noted that a great deal of bottom trouble was experienced during this campaign; very long fettles had to be carried out at not infrequent intervals.

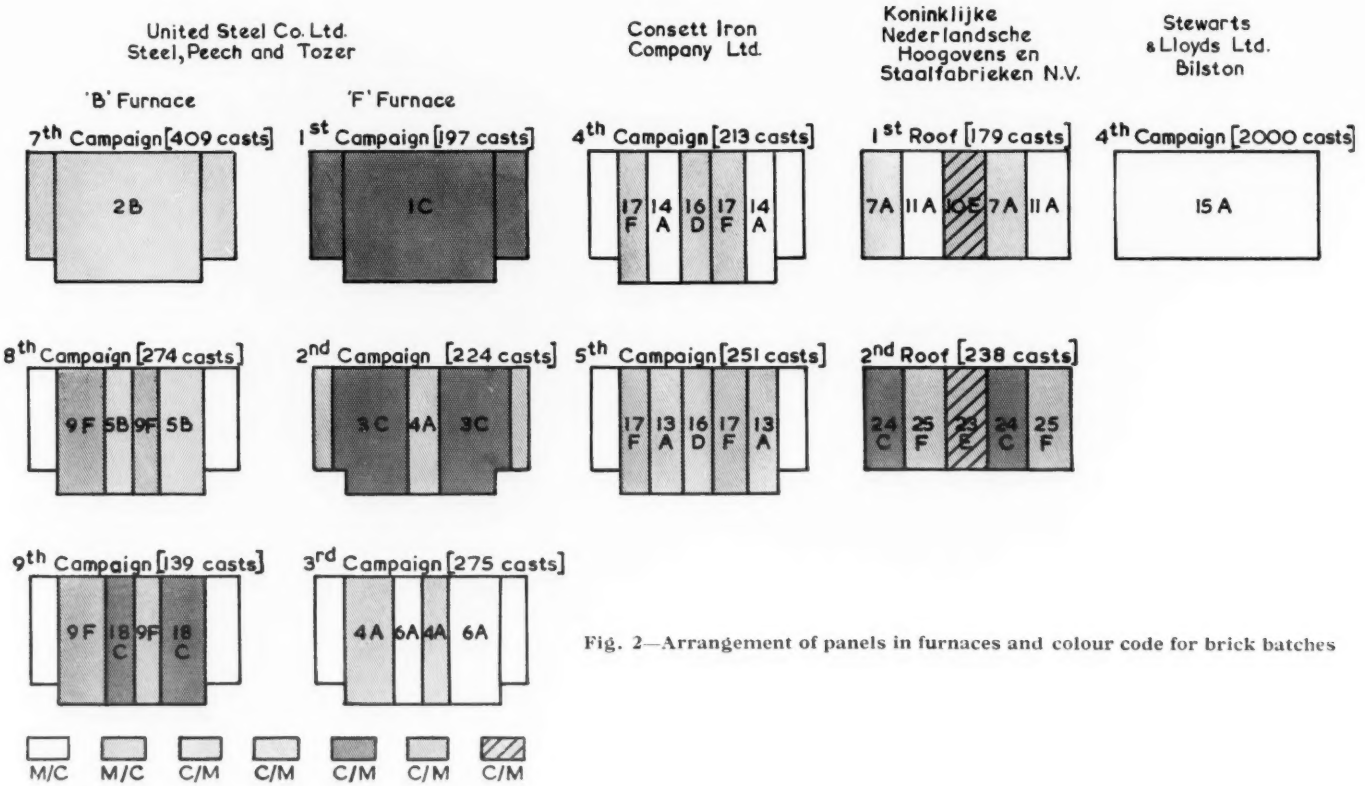


Fig. 2—Arrangement of panels in furnaces and colour code for brick batches

'B' Furnace

7th Campaign

The furnace was built as a 100-ton furnace but did not tap 100 tons until the 19th week of the campaign because crane capacity was not adequate until then. The roof was built completely of the red No. 2B chrome-magnesite brick with the conventional Austrian-type rib and intermediate suspension. The ribs consisted of two courses of 19½ in. × 7–6½ in. × 3 in. bricks and the intermediate bricks were 15 in. × 7–6½ in. × 3 in. and 15 in. × 7–6½ in. × 3¼–3 in. in size. Metal sheets were placed between brick faces in both transverse and longitudinal directions.

This oil-fired, single-burner furnace had the same main design features as the 'F' furnace, the roof span was 18 ft 3¾ in., and its length was 46½ ft. It was decided that once the roof springs had been tightened to take the load of the cold roof off the centres, no further adjustment would be made.

8th Campaign

The roof was now built of four panels using the green and red chrome-magnesite bricks Nos. 9F and 5B. Again the end panels on independent skewbacks were each one-third of the length of the main roof and the two inner panels supported on one spring-loaded skewback were each one-sixth of the length of the roof. A steel wire mesh was placed between each brick face in the transverse direction but steel plates were used in the longitudinal direction.

9th Campaign

The roof was again the Austrian-type suspended construction using green and brown chrome-magnesite bricks No. 9F and 18C in the four panels with wire mesh between all the bricks.

TRIAL FURNACE AT CONSETT

'J' Furnace

4th Campaign

Previous trials with all-basic roofs had been run at this plant and this was the fourth of these. The furnace was of single-burner, twin-uptake design, the roof being Detrick-suspended and flat from end to end. A new magnesite hearth was installed and fettled with magnesite in an effort to reduce the excessive cooling during fettles but after the first 6–8 weeks of the campaign the fettling time rose from under 1 h to 1½–2 h.

For the purpose of the refractories trials, the main roof was split into five panels but as the back skewback channels were in four sections, this meant that no individual panel was free to move according to its own expansion characteristics. The panels consisted of three types of brick: orange, yellow, and green, each 15 in. × $3\frac{7}{16}$ in. × $4\frac{3}{8}\frac{1}{4}$–$4\frac{7}{32}$ in. Orange 16D was a magnesite-chrome brick made from a natural magnesite, low in lime. This panel was placed in the centre of the roof to act as a control, in a position which tends to have the most severe erosion. Yellow 14A was also magnesite-chrome made from sea-water magnesite, whilst green 17F was a chrome-magnesite made from natural magnesite.

5th Campaign

This roof was virtually a repeat of the previous one except that the yellow magnesite-chrome type 14A was replaced by the blue 13A, which was a chrome-magnesite made by the same brickmaker from similar materials to that of type 14A.

TRIAL FURNACES AT IJMUIDEN

First Trial Roof

The 190-ton oil-fired furnace was fitted with twin burners. The roof bricks, 15 in. × 3½ in. × 4½ in. were suspended by the Detrick method, but the five trial panels did not completely cover the roof which was 46 ft long with a 22-ft span, because some chrome-magnesite bricks from the previous campaign were left in position above the whole length of the back wall. The blue chrome-magnesite brick No. 7A and the yellow magnesite-chrome brick No. 11A formed the outer panels and the striped green chrome-magnesite brick No. 10E was built in the central panel.

Second Trial Roof

In this campaign the roof construction was the same as in the first trial but the five panels covered the whole of the main roof; the striped green brick No. 23E formed the central panel but the brown and green chrome-magnesite bricks Nos. 24C and 25F were used for comparison in the other four panels.

TRIAL FURNACE AT BILSTON

'A' Furnace

This 60-ton hot-metal tilting furnace was oil-fired and built with a single air uptake. The main features of the roof construction, which have been described previously,[3] were that the tapping-side skewback channel was in three sections suspended from the furnace structure and supported by springs and that the rib and intermediate brick courses were not otherwise suspended but were held down and controlled by a restraining gear. The rib blocks, two courses wide, were 18 in. thick, and the ribs support four courses of intermediate bricks 12 in. × 5 in. × 3 in. A steel plate $\frac{1}{32}$ in. thick was used on each face of the roof bricks. During construction, the building proceeded from each end, the two ends being jacked apart to remove any irregularities due to the steel plates and this allowed the insertion of an extra course of blocks in the centre of the roof which was 57 ft long and had a 17-ft span. The whole roof was built with yellow magnesite-chrome bricks No. 15A.

Section 3—LABORATORY TESTS ON UNUSED BRICKS

Unused bricks were taken from each of the brick batches at the time the various roofs were being built. When the roof was of composite character consisting of rib and intermediate bricks, three rib and nine intermediate bricks of each brand were taken for testing, but where the Detrick method of suspension was in use, twelve bricks of each brand comprised the sample.

The following tests were made on each sample:

(a) *Complete Chemical Analysis*

This was carried out on samples obtained from the

intermediate bricks where rib bricks and intermediates were made from the same brick batch.

(b) *X-ray Examination*

A powder photograph was obtained from the same sample that was used for chemical analysis. From the photograph the approximate chrome/magnesia ratio could be deduced, the cell-sizes of the spinel patterns measured, and the matrix minerals identified.

(c) *Petrographic Examination*

Petrographic examination was carried out on similar samples to those submitted for X-ray and chemical analysis. Thin sections and polished sections of the unused brick were prepared and estimations made of the mineralogical composition of the material, of the grain sizes of the chrome and magnesite fractions, and of the degree of fracture of the chrome grains.

(d) *Apparent Porosity Determinations*

These were carried out on both intermediate and rib bricks by the evacuation method described in the British Standard 1902: 1952 *Method of Test for Refractory Materials*, para. 18A. Three results were obtained from each brick sample. One rib brick and three intermediate bricks were tested: in the case of a Detrick roof, three bricks were tested.

(e) *Permeability*

Permeability to air was measured on intermediate and rib bricks according to the procedure given in B.S. 1902: 1952, para 24A. The test pieces were cut in such a way that the direction of flow was parallel to the length of the brick.

(f) *Volume Stability at High Temperature*

This test was carried out on intermediate and rib bricks; test specimens were prepared as described in B.S. 1902: 1952, para. 27B. The test specimens were heated for 2 h at 1600° C in an oxidizing atmosphere and the percentage change in volume measured by a mercury volumenometer. A second series of test specimens was then heated to 1700° C in an oxidizing atmosphere for 2 h and the volume changes were measured as before.

(g) *Refractoriness-under-load Maintained Temperature Test*

This test was carried out on the intermediate bricks according to the method described in B.S. 1902: 1952, para. 26. Only the maintained temperature test was used, the specimen being held at 1600° C for 1 h, or alternatively until collapse had occurred. The test was carried out in such a way that the load of 28 lb/in² was applied in the same direction as that in which the roof pressure is applied, i.e. perpendicular to the tapered faces.

(h) *Bursting Expansion Test*

This test was carried out on specimens cut from both intermediate and rib bricks. The prism specimens had an area of 4 in² and the upper face was covered with 40 g of a standard mill-scale and heated for 1 h at 1600° C. The bursting expansion was recorded by measuring the average percentage increase in each dimension of the top face. Since this test is not easily reproducible, specimens of all the unused bricks were retained and the whole collection tested together in the same furnace. Tests were also made on samples as they arrived from the laboratories.

(j) *Cold Crushing Strength*

Cold crushing strength tests were carried out on intermediate and rib bricks, a minimum of six 3-in. cubes being used for each test and the cubes crushed by applying a pressure parallel to the length of the brick, i.e. by crushing perpendicular to the end faces. The testing procedure was similar to that recorded in B.S. 1902: 1952, para. 28C.

(k) *Thermal Shock Test*

This was carried out on intermediate and rib bricks according to the test procedure given in B.S. 1902: 1952, Appendix, p. 47.

(l) *Measurement of Creep*

A specimen in the shape of a cylinder 1 in. long and 1 in. dia. was maintained at 1300° C for 24 h under a load of 75 lb/in². Changes in the height of the specimen during this period were continuously recorded. Without removing the specimen from the apparatus the temperature was then raised to 1400° C and any changes in height again recorded over 24 h.

(m) *Measurement of Thermal Expansion*

At the British Ceramic Research Association the reversible thermal expansion was determined between room temperature and 1000° C, according to B.S. 1902: 1952, para. 29A. At the United Steel Companies' laboratories the thermal expansion was determined up to 1450° C, according to B.S. 1902: 1952, para. 30A.

(n) *Panel Spalling Test*

A panel of eight bricks formed the floor of a gas-fired furnace. The face of the panel could be heated to temperatures up to 1700° C, and the hot face could be subjected to a series of heating and cooling cycles from 1700° to 1100° C.

(o) *Oxidation-Reduction Test*

Specimens consisting of cylinders approximately 2 cm dia. × 5 cm long were cut from the intermediate brick specimens and heated to 1000° C in an oxidizing atmosphere. The lengths of the specimens were then measured and the specimens reheated at 900° C in a hydrogen atmosphere for 2 h. Since no significant increase in length or in friability of the roof brick specimens was observed, these results were not reported.

Observations

The results of these tests are shown in Table IV, in which the results from two laboratories on a brick batch are sometimes included to show the range of values obtained; results from a third laboratory have usually been omitted because they fall within the range of values included and show no discrepancies or anomalies.

The chemical analysis results show that the brick compositions fall within a wide range, e.g. the Cr_2O_3 content ranged from 14% to 37% and the magnesia from 64% to 36%. The only difficulty encountered in this test was that of obtaining a representative sample for one or two brick batches at two of the laboratories.

The apparent percentage porosity figures were

Table IV—RESULTS OF TESTS

Brick Number and Colour	1C (Brown)				2B (Red)			
Furnace and Works	'F' Furnace: Steel, Peech and Tozer				'B' Furnace: Steel, Peech and Tozer			
Roof Number	I				I			
Complete Roof or Panel	Complete				Complete			
Type of Brick	Chrome-Magnesite				Chrome-Magnesite			
Laboratory Number	1		2		1		2	
Chemical Analysis, %								
SiO_2	5·04				5·40		4·85	
Al_2O_3	13·22				12·73		11·10	
Fe_2O_3	11·86				12·08		10·55	
CaO	1·84				1·92		1·58	
MgO	39·02				41·08		43·50	
Cr_2O_3	28·34				26·25		27·80	
Loss	0·10				0·08		0·13	
	Ribs	Intermediate	Ribs	Intermediate	Ribs	Intermediate	Ribs	Intermediate
Apparent Porosity, %								
Mean	20·8	20·9	22·3	21·6	23·2	21·2	...	23·6
Range	20·1–22·3	20·0–22·4	22·1–22·4	20·8–22·4	22·4–24·1	20·7–21·7	25·2–25·6	22·3–24·7
Bulk Density, g/ml	3·05	3·06	3·02	3·04	3·02	3·06	2·90	2·93
Apparent Solid Density, g/ml	3·87	3·87	3·88	3·88	3·94	3·88	3·88	3·84
Permeability, c.g.s.	0·16	0·06	0·058	0·087	0·10	0·05	0·045	0·057
			0·167	0·080			0·034	0·169
Thermal Shock Resistance, cycles	25 +	25 +	5 to 25 +	6 to 22	25 +	25 +	30 +	30 +
Cold Crushing Strength, lb/in²								
Mean	4570	3390	...	...	4480	3930	...	...
Range	3830–5180	3130–3990	4130–4910	...	4080–4780	3400–4630	4695–4820	4040–4420
Volumetric Shrinkage								
1600° C	− 1·2	− 0·8	− 0·4	− 0·9	1·0	1·3	− 0·20	+ 0·30
1700° C	− 1·7	− 4·0	− 0·7	− 4·3	2·3	4·3	− 3·95	− 8·06
Refractoriness-under-Load	3·4% after 1 h	Sheared after 58 min	5% deformation in: 8 min; 19 min; 20 min; 25 min		Failed after 34 min		5% deformation after: 6 min; 11 min; 11 min; 32 min	
Bursting Expansion								
1600° C		2·8	2·6	2·1		7·2	5·4	2·8
1650° C		2·3	2·1	1·8		7·4		
Thermal Expansion								
20–1000° C	0·86		0·73				0·71	
20–1450° C			1·50				1·54	
X-ray Examination	Spinel 8·245 kX Magnesia Fosterite Monticellite		Spinel 8·245 kX Magnesia 4·201 kX Fosterite Monticellite		(Rib) Spinel 8·245 kX Magnesia Fosterite Monticellite		Spinel 8·247 kX Magnesia 4·202 kX Forsterite Monticellite	
Petrological Examination	Large red grains chromite some with black inclusions. Magnesia in matrix varied from light to dark brown. Rather high proportion of silicate present		Periclase crystals very small. Many coarse chrome grains fractured		Chromite dark red, excessive fragmentation. Magnesia in both coarse and fine fractions		Chromite ruby-red coarse up to 2·5–2·6 mm dia. Also in medium. Magnesia in coarse 7·5 mm dia. and fine fractions	

Brick Number and Colour	3 C (Brown)				4 A (Blue)			
Furnace and Works	'F' Furnace, Steel Peech and Tozer				'F' Furnace, Steel Peech and Tozer			
Roof Number	2				2			
Complete Roof or Panel	Panel				Panel			
Type of Brick	Chrome-Magnesite				Chrome-Magnesite			
Laboratory Number	1		2		1		2	
Chemical Analysis, %								
SiO_2	5·75		6·0		3·64		4·24	
Al_2O_3	14·05		11·6		13·26		14·10	
Fe_2O_3	11·05		10·85		9·41		10·62	
CaO	1·98		2·24		1·20		1·30	
MgO	39·30		41·5		50·88		44·60	
Cr_2O_3	27·32		27·4		21·27		24·10	
Loss	0·38		0·04		0·20		0·24	
	Ribs	Intermediate	Ribs	Intermediate	Ribs	Intermediate	Ribs	Intermediate
Apparent Porosity, %								
Mean	22·0	22·6	23·0	23·8	22·5	21·8	23·9	22·6
Range	20·6–23·0	21·1–24·0	22·7–23·3	23·3–24·2	22·4–22·7	21·2–23·4	23·8–24·0	22·2–23·0
Bulk Density, g/ml	2·98	2·95	2·97	2·93	2·94	2·98	2·89	2·96
Apparent Solid Density, g/m	3·84	3·80	3·85	3·84	3·79	3·83	3·80	3·83
Permeability, c.g.s.	0·08	0·03	0·072	0·05	0·06	0·13	0·080	0·130
Thermal Shock Resistance, cycles	25	25 +	5 to 30 +	10 to 30 +	25 +	25 +	30 +	30 +
Cold Crushing Strength, lb/in²								
Mean	4400	4520	...	...	4640	3160	...	...
Range	3770–5000	3050–5780	2460–3030	2460–3200	4100–5260	2820–3470	3030–3270	3970–3980
Volumetric Shrinkage								
1600° C	− 3·0	− 5·6	− 2·9	− 3·1	− 1·2	− 0·7	− 0·7	− 0·2
1700° C	− 8·7	− 8·2	− 7·3	− 5·1	− 3·8	− 3·4	− 1·8	− 2·2
Refractoriness-under-Load	Failed 1560° C	Failed 1560° C	5% deformation after 12 min; 12 min		...	Sheared after 46 min		5% deformation after 18 min; 20 min
Bursting Expansion								
1600° C		6·8	1·0	0·9		5·5	1·3	1·0
1650° C		5·8				4·0	3·0	1·4
Thermal Expansion								
20–1000° C	0·84		0·87		0·94		0·78	
20–1450° C			1·65				1·61	
X-ray Examination	Spinel 8·245kX Magnesia Forsterite Monticellite				Spinel 8·23kX Magnesia Forsterite Monticellite		Spinel 8·233kX Magnesia 4·200kX Forsterite	
Petrological Examination	Magnesia in fine fraction. Chromite grains fractured with considerable sesquioxide deposition. Some of the large chrome grains consist of aggregates of fine fragments with olivine confined to chrome grain boundaries		Most of chromite as deep red grains 2 mm dia. Forsterite present in above average amount as edging to chrome grains and as aggregates		Magnesia in both coarse and fine fractions. Two types of chromite: orange-coloured unfractured and dark-red, extensively fractured. Less olivine than usual		Magnesia present in both coarse and fine grades. Chromite also present in both fractions but mainly in former, this being dark red, free from inclusions. Forsterite round the chrome grains.	

Table IV—(*Continued*)

Brick Number and Colour	5B (Red)		6A (Yellow)	
Furnace and Works	'B' Furnace, Steel Peech and Tozer		'F' Furnace, Steel Peech and Tozer	
Roof Number	2		3	
Complete Roof or Panel	Panel		Panel	
Type of Brick	Chrome-magnesite		Magnesite-chrome	
Laboratory Number	1	2	1	2
Chemical Analysis, %				
SiO_2	6·26	6·50	3·89	3·89
Al_2O_3	8·63	9·20	9·97	8·43
Fe_2O_3	10·06	9·70	5·75	7·11
CaO	0·87	0·98	2·05	2·22
MgO	46·37	45·20	63·41	63·10
Cr_2O_3	27·15	28·2	14·55	14·90
Loss	0·18	0·14	0·38	0·28
	Ribs / Intermediate	Ribs / Intermediate	Ribs / Intermediate	Ribs / Intermediate
Apparent Porosity, %				
Mean	26·6 / 25·3	27·5 / 26·4	22·9 / 21·8	25·4 / 25·2
Range	26·1–27·4 / 24·2–26·6	27·0–28·1 / 26·1–26·6	22·3–23·5 / 20·0–22·9	24·9–26·1 / 23·2–25·2
Bulk Density, g/ml	2·88 / 2·90	2·79 / 2·82	2·88 / 2·90	2·76 / 2·80
Apparent Solid Density, g/ml	3·86 / 3·86	3·85 / 3·85	3·87 / 3·69	3·70 / 3·69
Permeability, c.g.s.	0·160 / 0·100	0·087 / 0·106	0·07 / 0·07	0·025 / 0·100 0·041 / 0·077
Thermal Shock Resistance, cycles	17 / 25 (12, 21) / (25, 25)	30 + / 30 + (4 test pieces)	25 + / 25 +	30 + / 30 +
Cold Crushing Strength, lb/in²				
Mean	1250 / 1730	... / ...	5910 / 4010	... / ...
Range	920–1580 / 920–2520	2720–3130 / 2490–2910	4320–8560 / 2670–5140	8450–9320 / 3650–4670
Volumetric Shrinkage				
1600° C	nil / − 0·5	+ 0·2 / + 0·9	− 1·7 / − 1·9	− 0·8 / − 0·9
1700° C	− 5·6 / − 5·6	− 6·8 / − 7·3	− 3·8 / − 3·6	− 1·5 / − 2·7
Refractoriness-under-Load	4·5% def. after 1 h 2·4% def. after 1 h	5% def. after 20 min Failed after 12 min	Sheared after 20 min	5% def. after 54 min Failed after 9 min Failed after 11 min
Bursting Expansion				
1600° C	8·2	4·4 / 3·5	9·0	0·4 / No change
1650° C	9·0	3·1 / 2·2	6·7	0·6 / 0·7
Thermal expansion				
20–1000° C	0·87	0·76	0·97	0·85
20–1450° C	...	1·44		1·54
X-ray Examination	Spinel 8·26kX Magnesia Forsterite Monticellite	Spinel 8·255kX Magnesia 4·200kX Forsterite	Spinel 8·21–8·29kX Magnesia Forsterite Monticellite	Spinel 8·226kX (mean) Magnesia 4·201 kX Monticellite
Petrological Examination	Chrome mainly unfractured. Magnesia in the fine fraction unevenly distributed. Marked development of olivine as large plates		Both coarse and fine magnesia. Chrome present as small crystals mainly without fracture. Very little olivine	Magnesia in coarse fraction up to 2·5 mm and in fines

Brick Number and Colour	7A (Blue)		9F (Green)	
Furnace and Works	No. 4 Furnace, Ijmuiden		'B' Furnace, Steel Peech and Tozer	
Roof Number	1		2 & 3	
Complete Roof or Panel	Panel		Panel	
Type of Brick	Chrome-magnesite		Chrome-magnesite	
Laboratory Number	1	4	1	2
Chemical Analysis, %				
SiO_2	4·30	3·24	4·42	4·40
Al_2O_3	13·59	(Al_2O_3 + TiO_2) 13·27	7·24	8·50
Fe_2O_3	9·26	11·67	13·65	11·2
CaO	1·94	1·63	0·75	0·93
MgO	48·82	49·42	38·05	39·50
Cr_2O_3	21·45	21·98	34·96	35·30
Loss	0·10	...	0·12	
			Ribs / Intermediate	Ribs / Intermediate
Apparent Porosity, %				
Mean	22·4	24·0	21·8 / 20·6	20·7 / 21·7
Range	21·2–23·7	22·2–24·8	21·1–22·5 / 20·3–20·9	19·3–22·0 / 21·0–22·1
Bulk Density, g/ml	2·95	...	3·12 / 3·18	3·13 / 3·12
Apparent Solid Density, g/ml	3·80	...	3·98 / 4·01	3·98 / 3·98
Permeability, c.g.s.	0·15	0·1–0·25	0·04 / 0·06	0·047 / 0·115 +0·087 / 0·068
Thermal Shock Resistance cycles	25 +	...	25 + / 25 +	30 + / 30 +
Cold Crushing Strength, lb in²				
Mean	2690	...	3020 / 2920	
Range	1970–4530	...	2860–3180 / 1810–3620	3780–3960 / 3330–3070
Volumetric Shrinkage				
1600° C	− 0·3		− 0·4 / − 0·3	+ 0·5 / + 0·2
1700° C	− 2·2		− 1·5 / − 1·7	− 1·4 / − 1·7
Refractoriness-under-Load	Sheared after 10 min		Sheared after 23 min, 2% subsidence after 1 h	... / 3·2% def. after 1 h, 5% def. after 39 min
Bursting Expansion				
1600° C	10·2		6·8	3·3 / 3·9
1650° C	7·4		6·0	2·0 / 2·8
Thermal Expansion				
20–1000° C				
20–1450° C				
X-ray Examination	Spinel 8·21–8·235kX Magnesia Forsterite Monticellite		Spinel 8·28kX Magnesia Forsterite Monticellite	Spinel 8·276kX Magnesia 4·202kX Forsterite small
Petrological Examination	Chromite fraction variable some fractured others unfractured. Magnesia present in both coarse and fine fraction. Forsterite mainly occurring as large aggregates associated with chromite		Chromite deep red mainly unfractured with a lot of inclusions. Forsterite round the periphery. Magnesia in fines only, opaque	Chromite grains 3·3.5 mm dia. ruby red. Many cracked Magnesia confined to fine fraction, dark brown. Smaller amount of bonding silicate than usual

Table IV—(*Continued*)

Brick Number and Colour	10E (Stripe Green)		11A (Yellow)		13A (Blue)		14A (Yellow)	
Furnace and Works	No. 4 Furnace, Ijmuiden		No. 4. Furnace, Ijmuiden		No. 1 Furnace, Consett		No. 1 Furnace, Consett	
Roof Number	1		1		1		1	
Complete Roof or Panel	Panel		Panel		Panel		Panel	
Type of Brick	Chrome-magnesite		Magnesite-chrome		Chrome-magnesite		Magnesite-chrome	
Laboratory Number	1	4	1	4	1	3	1	3
Chemical Analysis, %								
SiO_2	3·43	2·30	4·06	3·51	4·08	3·79	4·59	4·11
	(Al_2O_3 + TiO_2)		(Al_2O_3 + TiO_2)					
Al_2O_3	9·23	9·70	8·28	8·86	12·63	12·77	8·35	7·47
Fe_2O_3	13·29	12·77	7·50	6·90	10·01	10·33	6·82	6·83
CaO	1·19	0·71	2·07	2·26	1·28	1·36	2·48	2·55
MgO	47·85	51·83	61·90	62·34	51·00	49·33	60·58	64·53
Cr_2O_3	24·49	23·50	16·19	17·11	20·57	21·76	16·62	14·32
Loss	0·20	...	0·18	...	0·16	...	0·32	...
Apparent Porosity, %								
Mean	21·4	21·7	23·6	23·5	24·7	23·95	24·4	24·0
Range	20·8–22·0	20·7–23·0	22·0–24·7	22·7–24·3	23·3–25·4	22·60–25·8	23·9–24·8	20·8–26·6
Bulk Density, g/ml	3·02	...	2·85	...	2·89	2·87	2·80	2·81
Apparent Solid Density, g/ml	3·85	...	3·72	...	3·79	3·77	3·69	3·70
Permeability, c.g.s.	0·05	0·1	0·1	0·1	0·05	0·08	0·08	0·08
Thermal Shock Resistance, cycles	25 +		25 +		25 +	25 +	25 +	25 +
Cold Crushing Strength, lb/in²								
Mean	4400		4500		2030	2630	3840	3493
Range	3400–5500		4000–5080		1630–2440	2295–2875	2770–5530	2364–5070
Volumetric Shrinkage								
1600° C	+ 0·7		− 0·6		+ 0·3	...	0·6	− 0·54
1700° C	Nil		− 1·8		− 1·5	− 1·6 (1680° C)	− 1·8	− 2·4 (1680° C)
Refractoriness-under-Load	3·4% subsidence after 1 h at 1600° C		Sheared after 40 min		Sheared after 2 min		Sheared after 1 min	
Bursting Expansion								
1600° C	9·2		1·4		10·5	14·7	5·3	9·2
1650° C	9·4		2·0		11·2		5·5	
Thermal Expansion								
20–1000° C								
20–1450° C								
X-ray Examination	Spinel 8·245kX Magnesia Forsterite Monticellite		Magnesia Spinel 8·20–8·28kX Forsterite Monticellite		Spinel 8·22–8·245 Magnesia Forsterite Monticellite		Magnesia Spinel 8·26kX Forsterite Monticellite	
Petrological Examination	Chromite mainly unfractured, deep red, surrounded by forsterite. Magnesia in coarse and fine fraction		Two types of chromite, one, pale unfractured, the second deep red and fractured. Chromite fragments small 0·75 mm. dia. and below, coarse magnesia 1·25 mm dia. average		Chromite highly fractured. Fines in the matrix. Magnesia in the coarse fraction; opaque		Chromite deep red, highly fractured. Magnesia in coarse and fines; opaque	

Brick Number and Colour	15A (Yellow)	16D (Orange)		17F (Green)	
Furnace and Works	'A' Furnace, Bilston	Consett		Consett	
Roof Number	1	1 and 2		1 and 2	
Complete Roof or Panel	Complete	Panel		Panel	
Type of Brick	Magnesite-chrome	Magnesite-chrome		Chrome-magnesite	
Laboratory Number	1	1		1	3
Chemical Analysis, %					
SiO_2	3·77	4·5	4·18	4·92	3·98
Al_2O_3	8·30	9·54	9·67	8·84	9·13
Fe_2O_3	7·14	7·20	6·22	11·95	12·04
CaO	2·54	1·32	1·86	0·70	0·98
MgO	63·90	59·60	63·39	42·71	39·57
Cr_2O_3	14·40	17·17	14·89	30·72	34·17
Loss	0·13	0·20	...	0·27	...
Apparent Porosity, %					
Mean	19·9	21·2	21·0	21·6	20·65
Range	18·5–21·0	20·3–21·8	19·8–22·5	20·9–22·2	19·4–22·4
Bulk Density, g/ml	2·91	2·92	2·92	3·13	3·13
Apparent Solid Density, g/ml	3·69	3·68	3·67	3·94	3·94
Permeability, c.g.s.	0·04	0·06	0·08	0·03	0·07
Thermal Shock Resistance, cycles	25 +	25 +	25 +	25 +	25 +
Cold Crushing Strength, lb/in²					
Mean	5550	3370	2594	3770	2800
Range	5260–5870	2640–4380	2000–3210	3280–4310	1258–5300
Volumetric Shrinkage					
1600° C	− 0·3	+ 0·1	− 0·66	+ 0·75	+ 0·87
1700° C	− 0·5	− 1·2	− 1·68 (1680° C)	− 0·4	− 0·24 (1680° C)
Refractoriness-under-Load	Sheared after 56 min	Sheared after 27 min		1·9% subsidence after 1 h	
Bursting Expansion					
1600° C	4·8	3·9	4·94	11·6	12·1
1650° C	3·8	5·9		12·5	
Thermal Expansion					
20–1000° C					
20–1450° C					
X-ray Examination	Magnesia Spinel 8·20–8·28kX Forsterite Monticellite	Magnesia Spinel 8·24kX Forsterite Monticellite		Spinel 8·26–8·29kX Magnesia Forsterite Monticellite	
Petrological Examination	Chromite unfractured Fine chromite in matrix. Magnesia in coarse and fines, low forsterite content	Two types of chromite present pale-unfractured dark fractured. Fine chromite in matrix. Forsterite confined to magnesia aggregate		Chromite deep red with inclusions. Magnesia in fines only	

Table IV—(*Continued*)

Brick Number and Colour	18C (Brown)				23E (Stripe Green)	24C (Brown)	25F (Green)
Furnace and Works	'B' Furnace, Steel, Peech and Tozer				No. 4 Furnace, Ijmuiden	No. 4 Furnace, Ijmuiden	No. 4 Furnace, Ijmuiden
Roof Number	3				2	2	2
Complete Roof or Panel	Panel				Panel	Panel	Panel
Type of Brick	Chrome-magnesite				Chrome-magnesite	Chrome-magnesite	Chrome-magnesite
Laboratory Number	1		2		1	1	1
Chemical Analysis, %							
SiO_2	6·73		6·10		3·65	5·53	3·90
Al_2O_3	10·25		10·45		10·70	11·57	9·54
Fe_2O_3	12·40		11·91		12·47	13·33	12·0
CaO	1·55		0·98		1·12	1·21	0·85
MgO	39·95		37·00		47·90	35·93	41·64
Cr_2O_3	28·65		32·15		23·75	32·12	31·92
Loss	0·12				0·14	0·07	0·07
	Ribs	Intermediate	Ribs	Intermediate			
Apparent Porosity, %							
Mean	21·3	22·0	21·2	21·2	20·0	21·1	19·9
Range	20·4–22·5	21·6–22·5	19·7–22·9	20·7–21·6	19·3–20·4	20·4–21·5	19·6–20·2
Bulk Density, g/ml	3·06	3·01	3·09	3·08	3·07	3·09	3·19
Apparent Solid Density, g/ml	3·90	3·88	3·91	3·91	3·85	3·91	3·98
Permeability, c.g.s.	0·07	0·027 0·043	0·039 0·068	0·019 0·022	0·15	0·08	0·07
Thermal Shock Resistance, cycles	25 +	22, 25 +	12–30 +	15–30 +	25 +	25 +	25 +
Cold Crushing Strength, lb/in²							
Mean	3240	3140					
Range	2980–3580	2610–3800			2450–4090	1920–3550	2450–3550
Volumetric Shrinkage							
1600° C	+ 2·2	nil	+ 0·7	+ 0·7	+ 0·5	+ 0·4	+ 0·5
1700° C	− 1·5	− 3·0	− 4·4	− 6·6	nil	− 1·8	− 0·6
Refractoriness-under-Load	Sheared after 14 min		5% def. after 17 min 5% def. after 26 min		Failed after 29 min	Failed after 12 min	2·3% sub. after 1 h
Bursting Expansion							
1600° C	13·2		6·7	5·8	11·5	10·7	11·0
1650° C	11·6		4·5	5·7	14·1	10·0	10·1
Thermal Expansion							
20–1000° C							
20–1450° C							
X-ray Examination	Spinel 8·26kX Magnesia Forsterite Monticellite		Spinel 8·2608kX Magnesia Forsterite Monticellite		Spinel 8·245kX Magnesia Forsterite Monticellite	Spinel 8·26kX Magnesia Forsterite Monticellite	Spinel 8·276kX Magnesia Forsterite Monticellite
Petrological Examination	Chromite deep red with sesquioxide inclusions. High forsterite content. Magnesia mostly in the fines				Deep red unfractured chromite. Opaque magnesia. Rather small percentage of silicate matrix	Coarse and medium grade of Chromite. Fine magnesia. High silicate content	Coarse red chromite. Fine dark brown magnesia Pockets of silicate matrix

fairly consistent at 18–23%, but the value for batch 5B was rather high at 24–27%.

The cold crushing strength figures show differences from batch to batch and there was some difficulty in reproducing results at two of the testing laboratories. Discrepancies were found to be caused by the use of different packing material between the test specimens and the jambs of the crushing machines at the two laboratories. The use of $\frac{1}{4}$-in. thick cardboard ensured that the load was applied evenly to the test sample and consistent results could then be obtained. Uneven load application usually resulted in the recording of low crushing-strength values.

The refractoriness-under-load tests were not easily reproduced, even in the same laboratory, and so average values have not been given in Table IV, but a range of values or the results of each determination have been reported. A number of the brick specimens failed by shear when kept at 1600° C under the 28-lb/in² load long before the 1-h soaking period had elapsed, but a limited number of the bricks withstood this treatment and passed the test.

The volumetric shrinkage test results at 1700° C show that one brick was stable under this treatment but that others decreased in volume by as much as 8%; the volume stability of the bricks at 1700° C was generally poor and there is room for improvement in this property.

The thermal shock resistance test was generally unsatisfactory because there was very little difference in the behaviour of the various types in the test. The standard test is concerned with the behaviour of the brick specimens at temperatures up to 1000° C, but in the open-hearth furnace roof temperatures fluctuate between 1000° and 1700° C. The panel spalling test using this temperature range and also producing a temperature gradient along the length of the brick was therefore instituted.

The mineralogical examinations served to show whether the magnesia and chrome ore were in either or both of the fine and coarse fractions of the brick batch. The determination of the spinel cell size and the fissured nature of the chrome grain is an indication of the iron oxide bursting tendency of the brick.

BURSTING EXPANSION DETERMINATIONS

The results given in Table IV show that the bursting expansion results are not reproducible in different laboratories, in spite of the use of a standard sample of iron oxide. In fact, duplicate determinations on specimens cut from the same brick and made in the same gas-fired furnace on different days may also vary alarmingly. Factors that can influence the reaction of iron oxide with the brick include: (*a*) the standard test temperature (1600° C) is very near the melting point of magnetite (1590° C) and it has been found that magnetite does not always completely penetrate the specimen, and (*b*) variations in oxygen pressure may reduce the percentage of magnetite, the bursting agent in the iron oxide. Also the nature of the expansion is such that the upper face of the

test sample may become very irregular in shape and, therefore, it may be almost impossible to make an accurate measurement on the burst specimen.

If the bursting expansion of various brick samples is to be compared, it is desirable that specimens from each of the samples should be tested at the same time in a uniform atmosphere.

The bursting expansion of the samples of the trial roof bricks have been compared by heating specimens from 20 samples together at each of the following three temperatures: 1600°, 1650°, and 1700° C. Samples 8, 12, 19, and 20 were not taken from roof trial bricks but were from other bricks of roof quality and used in this particular test. Duplicate determinations at each temperature were carried out and measurements were carefully made by each of three skilled laboratory workers. The mean values obtained at each temperature and the overall averages are shown in Table V.

The final order of merit derived from the overall average is: 1C, 11A, 4A, 15A, 16D, 14A, 3C, 7A, 6A, 9F, 5B, 20D, 2B, 12C, 10E, 19F, 17F, 18C, 13A, 8.

Repeat experiments show that the most consistent results were obtained at 1600° or 1650° C and the results in Table V indicate that 1700° C appears to be too high a temperature for the test.

Although the average for all the magnesite-chrome specimens (6·6%) is lower than the average for all the chrome-magnesite specimens (9·8%), as would be expected, the chrome-magnesite samples Nos. 1C, 3C, and 4A gave low bursting expansions.

CREEP MEASUREMENTS AT 1300° AND 1400° C

It has been found that chrome-magnesite bricks change from a rigid to a deformable state in the temperature range 1300–1400° C and this change may influence the behaviour of roof bricks within 1–3 in. of the working face. It has also been suggested that pressures up to 70 lb/in² may develop in basic roofs. Therefore, the deformation under a compressive load of 75 lb/in² has been measured on specimens cut from the roof trial bricks. The cylindrical specimens 1 in. tall and 1 in. dia. were heated in a Pt/Rh wire-wound furnace between recrystallized alumina thrust rods. Pieces of platinum foil were placed between the test specimens and the thrust rods. The temperature was maintained within ± 1° C of the testing temperatures of 1300° and 1400° C for 25–30 h. The rate of deformation was measured at each temperature on the same test specimen during one heat-treatment and the reported creep values shown in Table VI are the average rate of deformation over a period of 20 h when the rate of deformation was approximately linear.

Table VI shows that there was a marked increase in the creep value as the temperature was increased from 1300° to 1400° C, but that the creep at 1400° C was still relatively small if the creep at 1300° C was only 0·01%.

Table V

BURSTING EXPANSION RESULTS

Brick No. and type		Percentage Bursting Expansion			Overall Average
		1600° C	1650° C	1700° C	
Brown	1C C/M	2·8	2·3	3·0	2·7
Red	2B C/M	7·2	7·4	15·4	10·0
Brown	3C C/M	6·8	5·8	7·8	6·8
Blue	4A C/M	5·5	4·0	5·9	5·1
Red	5B C/M	8·2	9·0	12·3	9·8
Yellow	6A M/C	9·0	6·7	9·6	8·4
Blue	7A C/M	10·2	7·4	7·0	8·2
...	8 C/M	15·2	12·2	17·0	14·9
Green	9F C/M	6·8	6·0	12·7	8·5
Striped Green	10E C/M	9·2	9·4	14·5	11·0
Yellow	11A M/C	1·4	2·0	7·0	3·5
...	12 C/M	9·0	9·1	12·2	10·1
Blue	13A C/M	10·5	11·2	16·8	12·8
Yellow	14A M/C	5·3	5·5	8·7	6·5
Yellow	15A M/C	4·8	3·8	7·2	5·3
Orange	16D M/C	3·9	5·9	8·7	6·2
Green	17F C/M	11·6	12·5	13·7	12·6
Brown	18C C/M	13·2	11·6	13·7	12·8
...	19 C/M	10·2	8·4	15·6	11·4
...	20 M/C	10·8	10·3	8·5	9·9

Table VI

CREEP VALUES

Brick No.		Creep, percentage deformation per hour	
		1300° C	1400° C
Brown	1C	0·05	F
Red	2B	0·02	F
Brown	3C	0·06	0·16
Blue	4A	0·02	0·08
Red	5B	0·04, 0·10, 0·09	0·18, F, F
Yellow	6A	0·03, 0·01	0·12, 0·1
Blue	7A	0·03	0·20
Green	9F	0·02	0·07
Striped Green	10E	0·01	0·03, 0·09
Yellow	11A	0·02	0·23
Blue	13A	0·04	F
Yellow	14A	0·03	0·13
Yellow	15A	0·01	0·05
Orange	16D	0·02, 0·02	0·08, 0·08
Green	17F	0·02	0·07
Brown	18C	0·06	0·14
Striped Green	23E	0·01	0·04
Brown	24C	0·02	0·20
Green	25F	0·02	0·10

Note: F = Specimen deforming at an increasing rate or tending to failure

PANEL SPALLING TEST

Test Procedure for Sample Bricks

Since the test panel was designed to comprise eight standard squares placed on end, it was first necessary to cut standard squares 9 in. × 4½ in. × 3 in. from the larger intermediate and rib roof blocks that were sampled from the various trial panels. These roof blocks were all tapered, so that the figures underlined in the second column of Table VII represent the average dimensions of the two ends. For each cycle in the test rig, the panel comprised one standard brick taken from a consignment of chrome-magnesite bricks not represented in the trials, while the other seven bricks were selected from two brands corresponding to the two panels being compared in each trial roof. The temperature of the test panel was then raised overnight to 500° C by the use of small burners, after which the main gas/air burners were lit and the furnace temperature was raised to 1700° C in 5 h. This temperature was maintained for 1 h; the gas and air were then shut off and the furnace was allowed to cool naturally. When cold, the bricks were carefully inspected for spalling cracks, and the results from this first part of the test are given in

Table VII

RESULTS OF SPALLING TESTS

Brick No.	Original size of bricks, in.	Results of heat-treatments		Expansion (+) or Contraction (−)
		After 1 h at 1700° C	After cycle test	
2B Red	15·0 × 2·9 × 8·4 15·0 × 2·9 × 6·7	No spalling cracks	2/4* typical spalling crack. Low burst	− 1·2
4A Blue	16·4 × 6·3 × 3·1 12·0 × 2·9 × 4·6	No spalling cracks	1/3 typical spalling crack, short cracks perpendicular to hot face	− 0·9
5B Red	12·0 × 8·2 × 3·0 19·5 × 2·7 × 6·8	No spalling cracks	Typical spalling cracks	− 1·4
6A Yellow	16·4 × 3·2 × 6·5	No spalling cracks	No spalling cracks. No burst	− 1·9
7A Blue	15·0 × 3·4 × 4·3	No spalling cracks	Typical spalling cracks. Mild burst	− 0·6
9F Green	11·9 × 3·0 × 6·7 19·8 × 4·5 × 2·6	No spalling cracks	2/4 typical spalling cracks. No burst	− 0·5
10E Striped Green	15·0 × 3·4 × 4·3	No spalling cracks	No spalling cracks. No burst	+ 0·2
11A Yellow	14·8 × 3·4 × 4·1	No spalling cracks	No spalling cracks. No burst	− 0·7
13A Blue	15·1 × 3·5 × 4·3	No spalling cracks	1/4 typical spalling cracks, 2/4 doubtful	− 0·2
14A Yellow	...	No spalling cracks	1/2 typical spalling cracks. No burst	− 0·7
15A Yellow	11·6 × 4·9 × 2·8	No spalling cracks	2/3 typical spalling cracks. No burst	− 0·1
16D Orange	15·1 × 3·5 × 4·4	No spalling cracks	Short cracks perpendicular to hot face. No burst	− 0·2
17F Green	15·0 × 3·5 × 4·3	No spalling cracks	3/4 typical spalling cracks. Low burst	+ 0·3
18C Brown	12·0 × 3·0 × 6·7 19·6 × 6·7 × 2·7	No spalling cracks	Typical spalling cracks. Mild burst	+ 0·1

*The fractions in column 4 indicate the number of bricks that cracked: e.g. 2/4 means that 2 out of every 4 bricks cracked.

column 3 of Table VII. None of the brands showed any sign of spalling.

The same test panel was reassembled and submitted to the second part of the test, which consisted in first coating the face of the test panel with a layer of mill-scale, 10 g being placed on each square inch. The panel was then reheated to 1700° C using the same temperature schedule as before. After the panel had been kept at 1700° C for 15 min, the gas only was turned off, thus enabling the combustion air to cool the furnace to 1100° C in 15 min; this cooling rate is the same order as that occurring in some open-hearth roofs. The gas was then turned on again and the temperature of the furnace raised to 1700° C in 1 h. The gas was again cut off and the test panel subjected to a total of three heating and cooling cycles, after which it was allowed to cool to room temperature when the bricks were examined.

This second, more severe part of the test resulted in many of the bricks showing a typical hairline spall crack parallel to and 2–4 in behind the hot face. The results from this second part of the test are grouped in column 4 of Table VII.

The last column of Table VII gives the changes in dimensions of the hot face of the bricks after the completion of the first part of the test, i.e. after the hot face without slag addition had been maintained at 1700° C for 1 h. The measured expansion or contraction of the hot face as shown in Table VII is in fairly good agreement with the volume changes measured in the tests using the standard P.L.C. test procedure at 1650° and 1700° C.

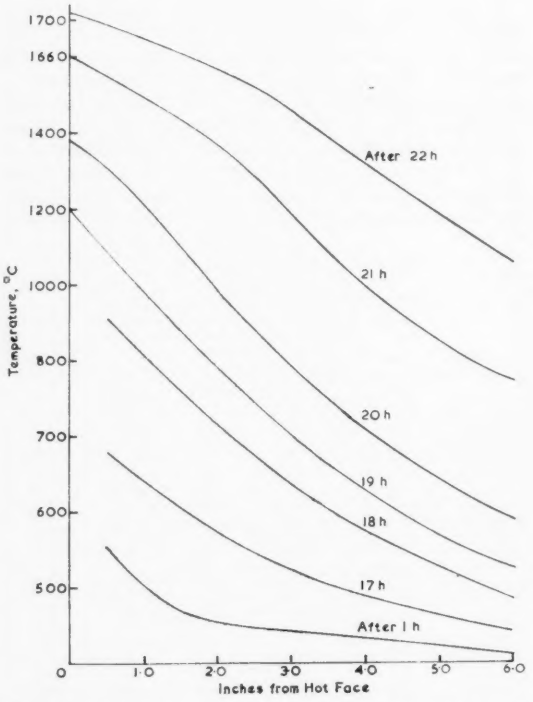


Fig. 3—Temperature gradients during heating up of test panels

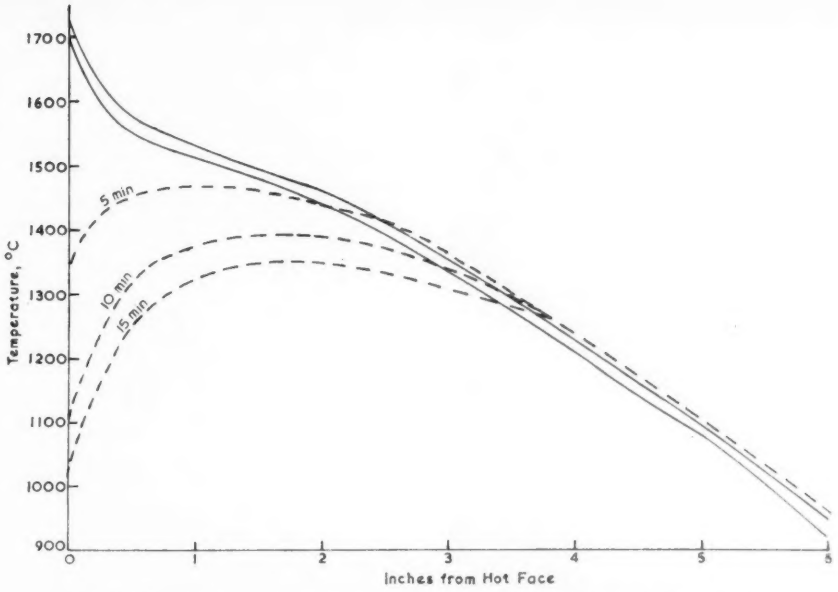


Fig. 4—Temperature gradients in test panel after cooling in forced air

Observations on the Panel Test

After the second part of the test, the bricks could be classified into three groups. Group I consisted of those bricks that showed no spalling cracks after three heating and cooling cycles with mill-scale addition; this group comprised types 6A, 10E, 11A, 16D, and 19F. Group II contained those types in which some but not all the bricks forming the test panel showed cracks; this intermediate group comprised types 2B, 4A, 9F, 13A, 14A, 15A, and 17F. Group III consisted of those types that had the highest spalling tendency, all the bricks in each panel having spalled; this group comprised types 5B, 7A, 8, 12, and 18C.

It is interesting to observe that three magnesite-chrome bricks (types 6A, 11A, and 16D) were included in Group I, with the two chrome-magnesite bricks, since straight magnesite bricks generally show low spalling resistance.

Additional Tests

It was decided to ascertain how many heating and cooling cycles the bricks in Group I could survive before they showed cracks; accordingly the samples from these five types of brick were subjected to a second series of three heating and cooling cycles, without further mill-scale addition. After six heating and cooling cycles in the test rig, it was found that all the five types of bricks that had survived the three cycles were now cracked. These results would indicate that any type of basic brick now being made, when incorporated in an open-hearth roof, would develop a spalling crack comparatively early in the campaign unless the hot-face temperature of the roof was rigidly controlled so that temperature fluctuations were virtually eliminated. Although the test was stringent in that the heated face of the brick was heated and cooled quickly to 1100° C six times, on the test evidence it can be stated with some confidence that with every grade of chrome-magnesite and magnesite-chrome brick used in the trials, the basic roof would be extensively cracked after the first few heats if the hot-face temperature had been allowed to fall in the region of 1100–1200° C.

The temperature gradient through the test panel has been determined using a chrome-magnesite panel of standard squares with thermocouples at $\frac{1}{2}$, 2, and 6 in. behind the hot face. These results are given in Figs. 3 and 4. Figure 3 shows the temperature gradients through the test panel at various times during the heating-up period. It will be seen from Fig. 4 that, whilst the hot-face temperature showed marked fluctuations, the temperature 2–3 in. behind the hot face remained fairly constant during the test; the crack usually appeared at this distance behind the hot face. It is possible that movement inside the brick caused by the thermal expansion and contraction of the grains in this range of fluctuating temperature, in contrast to the rigidity of the zone at constant temperature, has set up stresses of sufficient magnitude to crack the brick.

Section 4—FURNACE CAMPAIGNS AND DESCRIPTIONS OF ROOFS AND PANEL THICKNESSES AT THE END OF THE CAMPAIGN

CONSETT

4th Roof Trial

The life of this roof was 13½ weeks or 213 casts. After the furnace had been in service for 3 weeks, it could be seen that about a quarter of the roof had slabbed. This effect had started over the charging doors and had spread to the crown. There was also

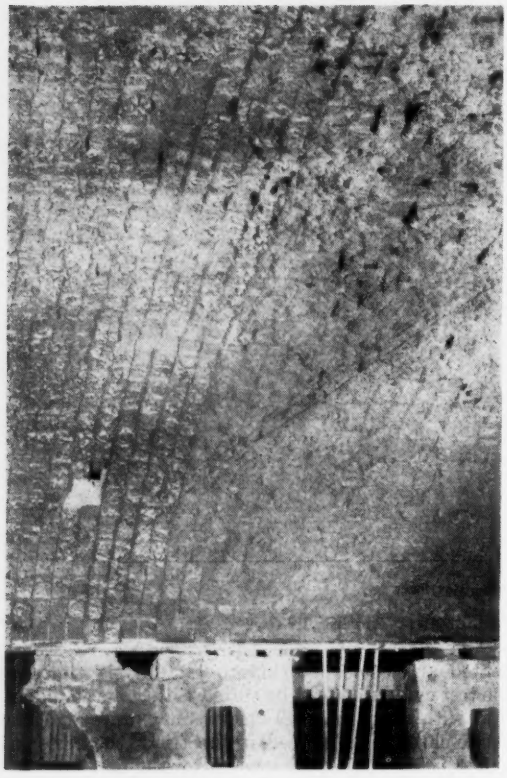


Fig. 5—A Consett roof at the end of the campaign, showing differences in the appearance of the glazed magnesite-chrome and the 'dry' chrome-magnesite panels

some slabbing over the back wall and this gradually spread over the roof. A second slabbing was observed in the 6th week. The furnace went out of operation because the front of the roof became so thin that the castings were red-hot, and the roof started to buckle and finally cracked open. Earlier in the campaign there had been a failure in the cooling-water system, with the result that water was sprayed over this front part of the roof.

The panels could be distinguished as the roof cooled down: the green chrome-magnesite brick had a dry surface appearance, but the orange and yellow magnesite-chrome bricks showed a fused and shiny surface (*see* Fig. 5). Half of each panel was dropped to expose the centre-line across the arch, and each brick along the centre-line of each panel was measured. The contours are shown in Fig. 6, where it can be seen that the green chrome-magnesite bricks were thicker than both the corresponding magnesite-chrome panels of yellow bricks. Although panels of yellow and orange bricks cannot strictly be compared, it would appear that there was little to choose between the behaviour of these bricks. The yellow brick contained sea-water magnesia and the orange contained natural magnesia. The question then arose as to whether the superiority of the green panels was due to the type of brick, its raw materials, or its method

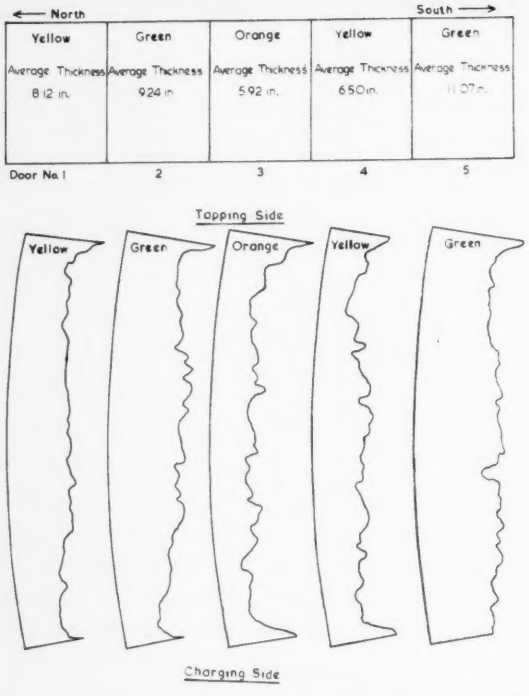


Fig. 6—Contours of panels in all-basic roof trials: 4th roof after 213 casts

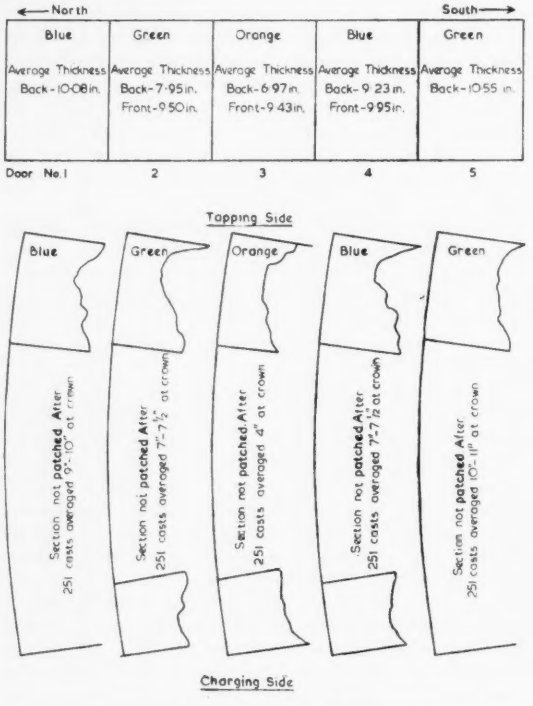


Fig. 7—Contours of panels in all-basic roof trials: 5th roof, patched after 143 casts, rebuilt after 251 casts

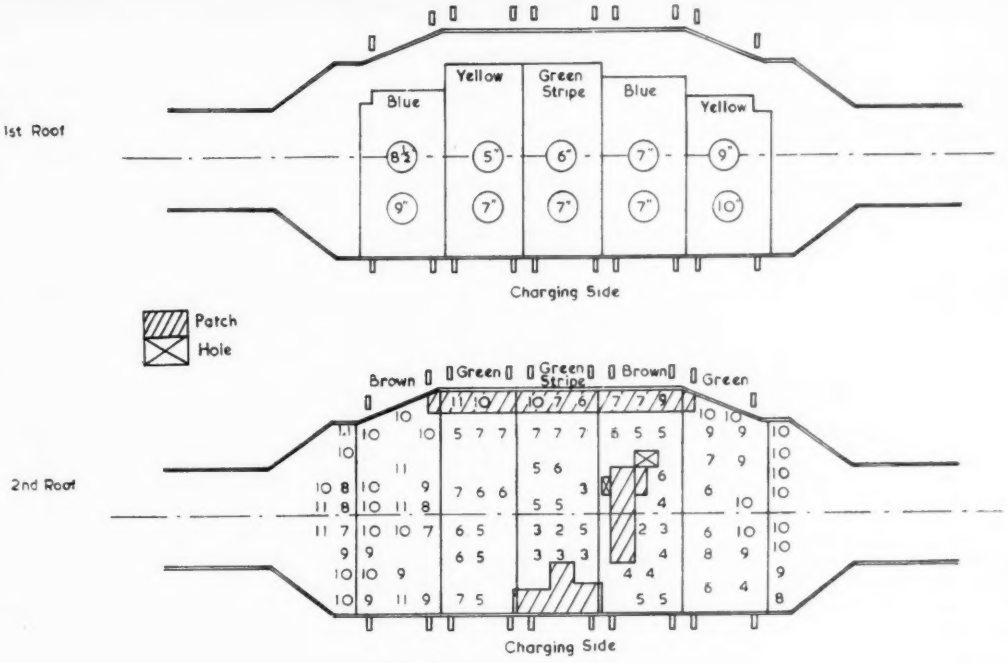


Fig. 8—Ijmuiden furnace

of manufacture. As the first of these variables was thought to be the most important, it was decided to replace the yellow magnesite-chrome panels with blue chrome-magnesite bricks.

5th Roof Trial

The furnace made a total of 251 casts (about 15 weeks) and during the campaign there was no obvious period when slabbing of the roof took place.

After 10 weeks and 143 casts, it was necessary to take the furnace out of production to repair the checkers, and it was decided to patch the roof where it had worn thin over the back and front walls; 16 courses of bricks were replaced along the back of the roof, each panel was patched with its appropriate type of bricks, and the thickness of the roof was carefully measured both at the back and front positions. The results are shown in Fig. 7. The centre magnesite-chrome panel of orange brick was thinner than the other panels, above the taphole, but not at the front. In this trial a blue chrome-magnesite brick had been used instead of the yellow magnesite-chrome brick used in the previous campaign, and this blue brick was at least as thick as the green chrome-magnesite brick. When the furnace roof was finally dismantled following an unexpected collapse of a small area of the crown of the orange panel, measurements were made in the centre of the panels which confirmed the previous findings. The orange magnesite-chrome panel made with natural magnesite now averaged only 4 in. thick, but the chrome-magnesite panels were thicker. Both blue and green chrome-magnesite bricks had worn back by about the same amount and it was not possible to distinguish between their performance. The appearance of the panels was again different in that the magnesite-chrome panel had a fused shining surface but the chrome-magnesite panels had a 'dry' crumbly surface. Some of the bricks now had cracks parallel to the working face and the roof had worn back because the ends of cracked bricks had fallen into the bath.

The conclusion drawn from these trials was that under the rather severe operating conditions at this plant (i.e. cooling down to 1100–1200° C at most fettles), chrome-magnesite bricks are superior to magnesite-chrome, presumably because they are better able to withstand temperature fluctuation.

IJMUIDEN

1st Roof Trial

The furnace was taken out of production after 179 casts because of the failure of the ramps and uptakes that had been left in from the previous campaign. The roof had slabbed in all areas and it was not possible to see any demarcation lines between the various panels. The surfaces of all the bricks had a slightly fused appearance, and there was no difference in appearance between the yellow magnesite-chrome brick and the blue and striped green chrome-magnesite bricks. The brick thickness was measured by removing areas of bricks from the centre of each panel and from the front portion, about 2 ft from the front wall of each panel. About 20 bricks were measured from each position and the average thickness of each patch of 20 bricks was recorded as the thickness at that position. The results given in Fig. 8 show that although the thinnest point was the centre of the yellow magnesite-chrome panel, the roof

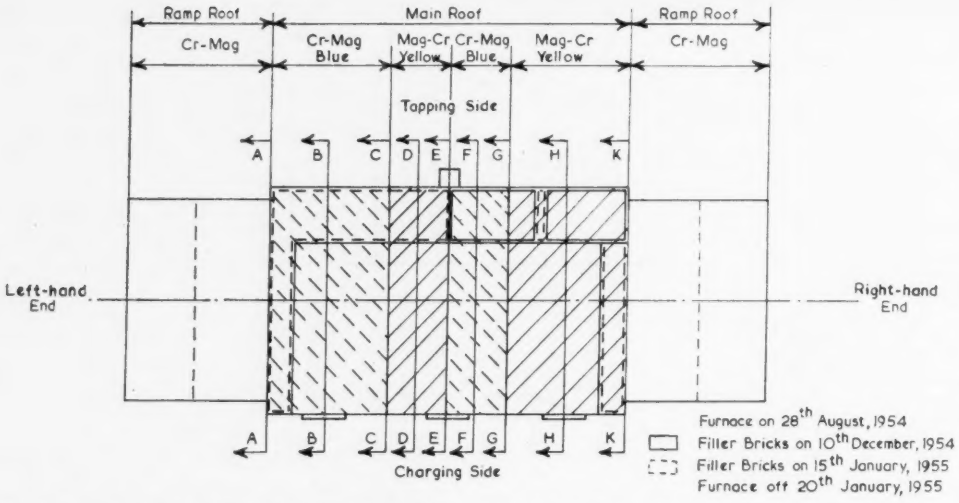


Fig. 9—Plan showing positions of contour sections: 3rd ' F ' all-basic furnace, Steel, Peech and Tozer

had worn evenly over the panels and it was not possible to distinguish between the performance of the yellow magnesite-chrome and the blue chrome-magnesite bricks.

2nd Roof Trial

The furnace made 238 casts when the average for the shop was about 190 casts. During the campaign the roof had been patched at the front of the centre panel, along the back of the three central panels, and in the centre of the brown chrome-magnesite inner panel. At the end of the campaign the patches could be seen very plainly and two small holes had formed at the edge of the patch in the brown brick panel, but the panels could not be distinguished from each other by visual examination; all the brick types had the same appearance, the roof having slabbed at all positions. The bricks were carefully measured and the thickness of the roof in inches is shown in Fig. 8. The inner panel of green chrome-magnesite bricks was intact and thicker than the remaining bricks in the corresponding panel of brown bricks, but the brown brick panel was thicker than the green brick panel if the outer panels are compared.

It was considered that the green brick gave better service than the brown brick, but that both bricks gave good service since the life of the roof was above average and since the central panel of striped green bricks had worn very thin. The bricks had cracked parallel to the hot face; some bricks had two such cracks, and the ends of cracked bricks had fallen into the bath during the campaign.

STEEL, PEECH AND TOZER

' F ' Furnace

The first and second roofs on this furnace were not panelled and the campaign lives were 197 and 224 casts respectively. It was not possible to obtain measurements of the roof thickness at the end of these campaigns, but in both cases quite severe slabbing of the bricks occurred, the slabbing being particularly severe in the first campaign. It was considered that the slabbing was associated with the locking of the roof lever system, with the result that adjustment of the roof did not take place and excessive pressure was placed on the roof bricks. There was no excessive bursting expansion and the bricks had sheared sharply about 2–3 in. behind the hot face. The slabbing was uniform across the main roof and was repeated during the campaign. After 97 casts in the first campaign the furnace was shut down to repair the chill end wall and slag pocket arches; this necessitated cooling down the roof and probably helped to increase the slabbing of the bricks. The poor life of the second roof was considered to be associated with the sub-standard high-temperature properties of the brown brick.

3rd Roof Trial

The furnace made 275 casts in 20 weeks. There was nothing to choose between the blue chrome-magnesite and the yellow magnesite-chrome bricks during the first 100 casts, but during this time slight slabbing took place along the front and back of the roof. External roof-temperature measurements suggested that after 152 casts the thinnest portion was over the back wall in the outer yellow brick panel, and at 199 casts this panel was showing dull red for 3–4 ft from the backwall skewback. After 206 casts filler blocks were placed along the back of the roof over the outer yellow panel and also along the back of the central blue brick panel. It was not necessary to extend filler blocks along the back of the outer blue and central yellow panels until the 268th cast. The campaign ended when an area of the outer yellow panel adjacent to the central blue panel became too thin for operation to be satisfactory. When the furnace had cooled and the panel thicknesses were carefully measured a hole had appeared at the back of the yellow outer panel. The roof contours (Figs. 9 and 10) show that at the back and front of the central panels the blue bricks were thicker than the yellow bricks; this fact, coupled with the appearance of the hole in the yellow brick panel, indicated that

the blue chrome-magnesite bricks gave a better performance than the yellow magnesite-chrome bricks during this campaign. All brick samples taken from this roof were badly cracked parallel to the working face; the appearance of the panels was very similar in the centre of the roof but the magnesite-chrome bricks were slightly fused over the back and front walls.

'B' Furnace

7th Roof Trial

The furnace made 409 casts; the first 279 were 80-ton and the remaining 130 were 100-ton casts. The roof was in excellent condition during the early operating weeks and no slabbing was noted during the first six weeks of the campaign, when 105 casts were made before a holiday shutdown. After 105 casts the roof contour was even but the surface was rough owing to iron oxide growth. About three to four weeks after production began again after the holiday, slabbing started over the doors and gradually spread over the roof. Repeated repairs were made to the front-wall panels and renewal of the target area of the uptake at the right-hand end of the furnace was necessary during the campaign.

Filler blocks were not used until 360 casts had been made; these fillers were not special shapes and the additional life of 49 casts before the campaign ended was rather disappointing. Shortly before the end of the

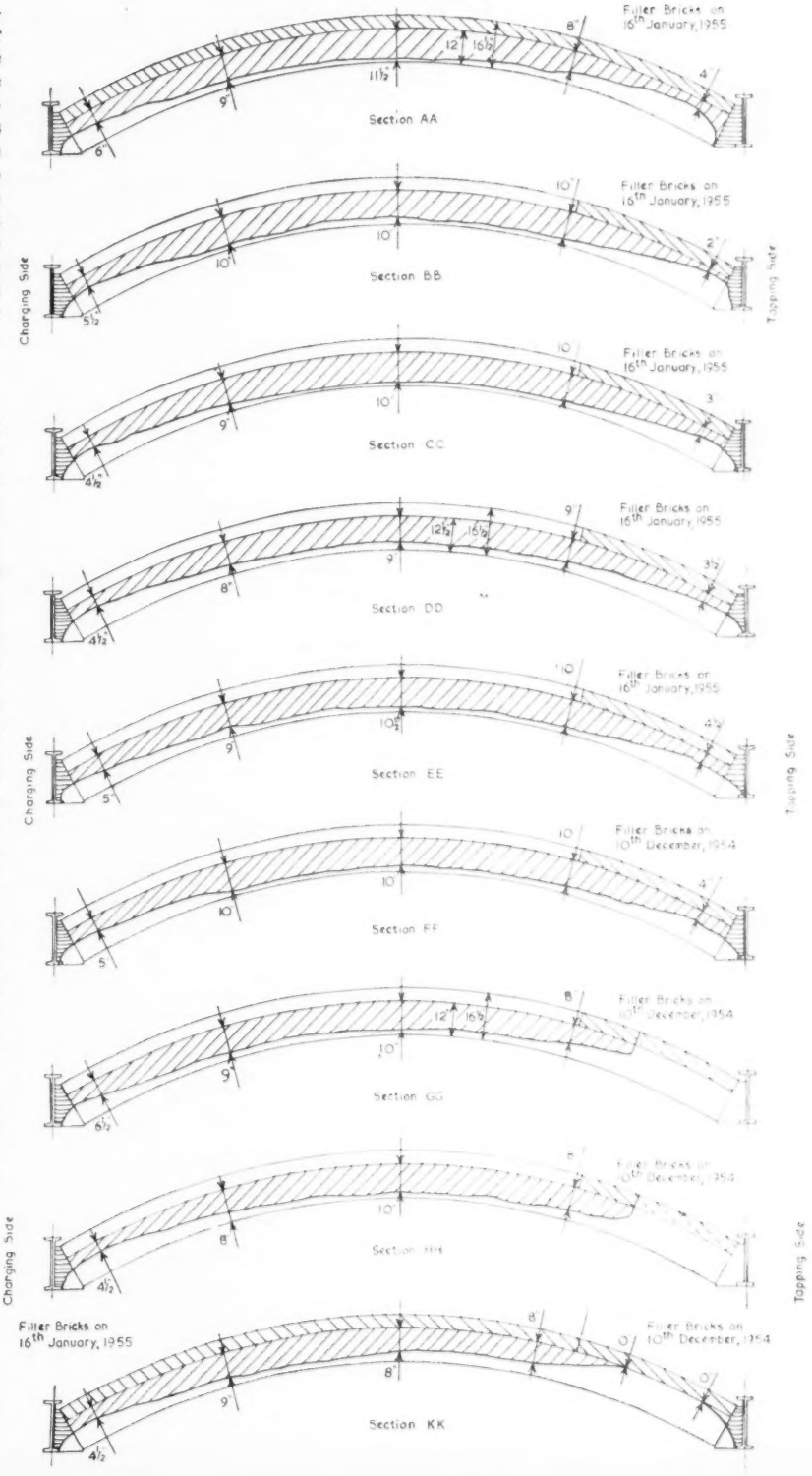


Fig. 10—Contour sections, showing wear on 'F' all-basic roof, Steel, Peech and Tozer

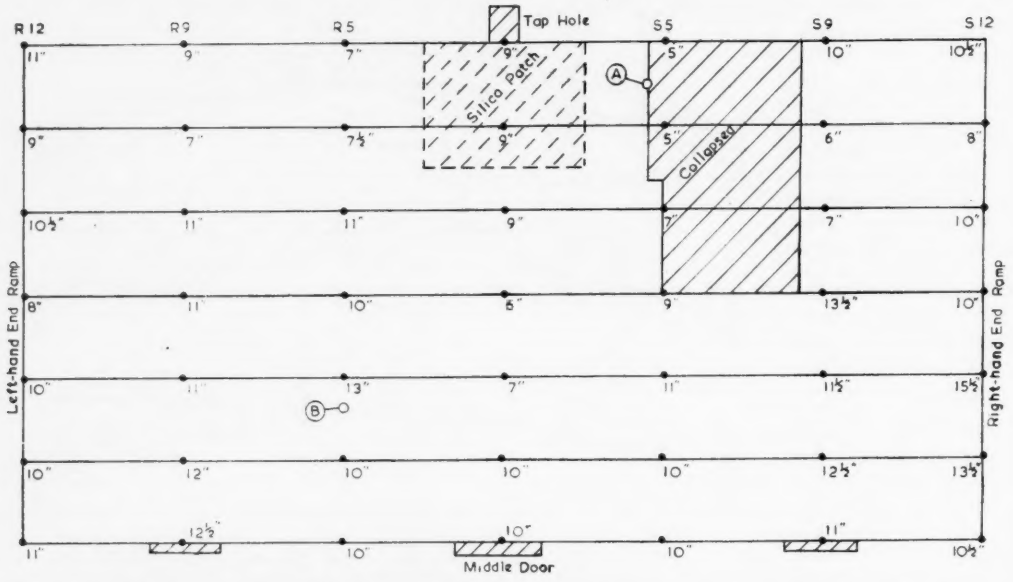


Fig. 11—Residual rib thickness at the end of the 7th campaign: 'B' furnace, Steel, Peech and Tozer (original thickness 19½ in.)

campaign a patch of brickwork over the taphole collapsed and was replaced by tarred silica bricks. After the 409th cast a large area in the right-hand side of the centre-line of the furnace collapsed and the furnace was taken out of production. Residual brick thicknesses are given in Fig. 11 and samples were taken from positions marked *A* and *B*, the thinnest and thickest parts of the roof. The average thickness for the whole of the remaining ribs was 10 in. out of an original 19 in. and, even in the worst area, 8½ in. remained. The area of collapse was the only area where the filler blocks had become exposed as the working face.

8th Roof Trial

The furnace made 274 casts in 20½ weeks and was interrupted after 28 casts for the summer shutdown. A considerable number of trials using oxygen for combustion were carried out and after 122 casts some wear was noted across the centre of the roof, but equally divided between the two central panels. After 179 casts the roof was examined carefully during a back-wall repair and no major difference in thickness between panels was estimated. It afterwards became apparent that the roof over the back wall was showing the greatest wear, particularly at

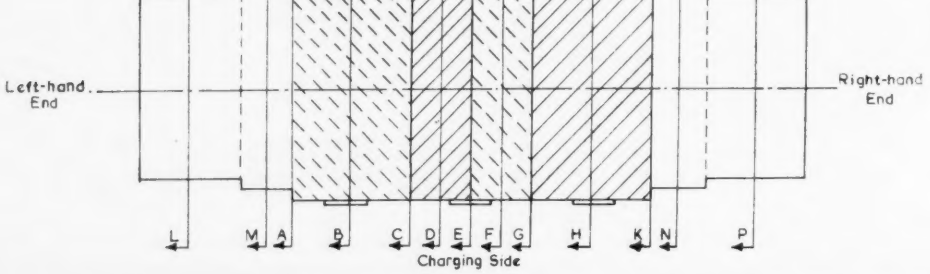


Fig. 12—Plan showing positions of contour sections: 8th, B' all-basic furnace, Steel, Peech and Tozer

the back of the outer red brick panel and in the sloping ramp at that end of the furnace. After 211 casts the filler blocks were placed over the whole of the roof and the sloping ramps. The fillers for the green brick panels were of special shape to fit between the ribs, but those for the red brick panel were 9-in. chrome-magnesite squares. After 274 casts the furnace was taken out of commission owing to collapse of the intermediate courses in the outer red brick panel over the back wall. The residual brick thicknesses are shown in the contour in Figs. 12 and 13, where it will be seen that the inner panels had worn to the same thickness.

The appearance of the hole in the outer red brick panel may have been caused by the uneven working of the furnace, but the green bricks were slightly thicker than the red bricks in other corresponding parts of the outer panels and, therefore, the green brick was probably slightly better than the red brick in this trial. There was no difference in the appearance of the panels: the roof had slabbed in all positions and brick samples again showed cracks parallel to the working face.

9th Roof Trial

The furnace was taken off production after 139 casts, after an unsatisfactory campaign.

After two or three weeks it was observed that the brown chrome-magnesite bricks, particularly over the right-hand end door and in the outer panel, were slabbing badly, but the green brick panels were sound. A continuous external roof temperature record was kept for most of the campaign and this record suggests that slabbing took place between the 35th and 37th casts, and again between the 80th and 85th

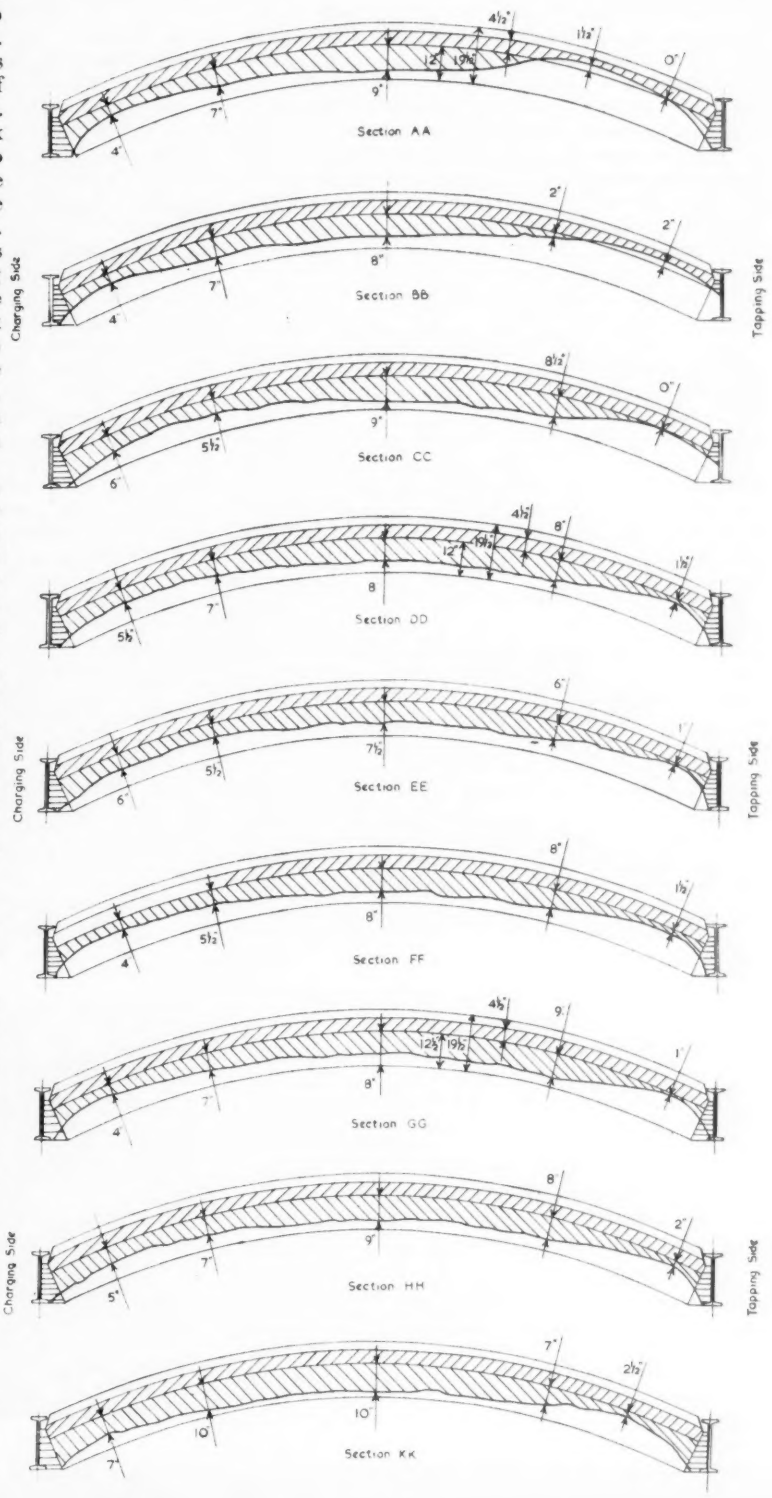


Fig. 13—Contour sections, showing wear on 'B' all-basic roof, Steel, Peech and Tozer

casts. Thin patches were noted on the roof before the 100th cast; some of the originally 12-in. intermediate bricks over the right-hand door and in the adjacent end ramp were slipping down. After 105 casts it was necessary to patch the right-hand ramp because of the loss of one intermediate ring; this was repaired with 9-in. silica bricks on end, arched across the ribs. Further similar repairs were made on this right-hand end ramp. After 111 heats, the whole of the right-hand half of the furnace, which included the outer brown brick panel and the inner green panel, was covered with silica bricks as fillers because, after completing the ramp repairs, intermediate brick courses in the outer brown brick panel had fallen into the furnace.

After 139 casts the furnace was taken out of commission primarily to repair the checkers after the failure of a reversing valve had resulted in the collapse of the left-hand end checker filling. As the furnace cooled down, however, the intermediate brick courses in the left-hand end of the roof and ramps began to slip and fall into the furnace; finally, practically all the intermediate bricks on the left-hand end had fallen into the furnace but the right-hand end was now strong, being a zebra construction of basic ribs and silica intermediates. The rib bricks in the two panels in the left-hand end of the furnace, the large outer green brick panel, and the small inner brown brick panel were measured, but the right-hand end was not measured because the wear on the basic brick had now probably been affected by the presence of the silica intermediate fillers. It was not possible to compare corresponding panels in this trial, but the relative thicknesses of adjacent ribs (the last green brick rib and the first brown brick rib) indicated that the green bricks had worn away at a slower rate than had the brown bricks. The thicknesses at corresponding positions of these ribs, which were originally 19½ in., were:

	Charging Side	Middle		Tapping Side
Green Rib	12½	13½	14¾	14½	11¼
Adjacent Brown Rib	10¾	10½	12½	13¼	11

Although the roof bricks had been loosely held because of a mechanical failure, the observed slabbing of the brown bricks and the contour measurements both indicated that the green chrome-magnesite bricks gave better service than the brown bricks.

BILSTON

Furnace 'A'

This furnace was taken out of service after 1989 heats because the furnace hearth needed to be renewed, the roof having considerable life remaining in it. The roof had been built with yellow magnesite-chrome bricks. The results of this campaign confirm the behaviour of the same brands of bricks in the previous campaign of 2205 casts. It should be noted that this brand of brick has not given such outstanding service in other furnaces during their trials.

The roof temperature in this furnace is very rarely below 1600° C, and after 350 casts the roof had been cooled only five times for minor repairs to other parts of the furnace. The roof was then in excellent condition. The skewback springs are very carefully adjusted as the furnace cools so that the roof contour is maintained. The roof was inspected during the holiday shut-down after completing 959 heats: during cooling some slabbing had occurred in two areas of 12 ft × 3 ft and 3 ft × 1½ ft, where the roof thickness was now reduced by 4 in. to 6 in. The roof had the appearance of a monolith and was covered with very small stalactites (Fig. 14); a viscous liquid had been formed and had tended to drop from the roof. This roof condition was quite different from that seen on any of the other trial roofs, even when the same brand of brick had been used, but it was very similar indeed to the condition of the previous roof in the same furnace. After 1298 casts the roof had a rough appearance caused by the stalactites and the slabbing of some of the ends of bricks. The minimum thickness was now 7½ in., but areas 12 in. thick still persisted. After 1530 casts the roof still appeared to be in reasonably good condition and after 1650 casts the minimum intermediate brick thickness was 4 in. (original thickness 12 in.), but with the 4½-in. filler blocks now placed in position the campaign was expected to last a considerable time longer. After 1820 casts the roof was still reasonably good condition and the furnace was now making 22–23 casts per week.

OBSERVATIONS

From the results of the panel trials it is difficult to place the bricks in a definite order of merit, but it is significant that the green bricks that gave good service at three plants were different batchs of chrome-magnesite bricks made by the same manufacture. In spite of the excellent service of the yellow magnesite-chrome brick at Bilston, the panel trials indicated that magnesite-chrome bricks were really no better than chrome-magnesite bricks in the O.H. furnace roofs; in fact the blue chrome-magnesite bricks were either better or equal to the yellow magnesite-chrome

Fig. 14—Appearance of Bilston roof during the campaign, showing small stalactites on the glazed surface

bricks in panelled roofs. These two types of brick were made by the same manufacturer.

Section 5—EXAMINATION OF THE USED BRICK SAMPLES

Many samples of used bricks have been taken from the trial roofs. These bricks are usually cracked parallel to the hot face, some containing two such cracks and showing a zoned effect, the zones being parallel to the working face. The working surface may be friable or slightly fused, but the original brick texture has been completely altered in this first zone. About 2–3 in. from the working face, a dense hard zone has usually formed, but the original brick structure is still apparent. These used brick samples have been examined by chemical, petrological, and X-ray methods to determine the chemical and mineralogical composition of the specimens at different distances from the working face. The percentage apparent porosity and the deformation under load at high temperatures have also been determined on numerous samples. Except in the case of Bilston 'A' furnace roof, it has been found that the results obtained from bricks taken from different panels in a roof, and also from bricks taken from different roofs, are very similar indeed, different brands behaving in a similar way in different roofs. The results are also in agreement with the work of Trojer.[6] Representative results will, therefore, be described, but the results obtained from all the brick panels will not be given.

Roof Brick taken from 'B' Furnace, Steel, Peech and Tozer, at the end of the 7th Campaign

Figure 15 shows cracks in two sections of the red brick. This brick sample was taken from position *B* in Fig. 11, between the left-hand and middle doors, half-way between the centre and front of the furnace. This intermediate brick was 7½ in. long; a large crack had developed about 2 in. behind the working face and other smaller cracks had also formed.

Specimens were obtained by cutting the brick parallel to the working face, the cutting positions

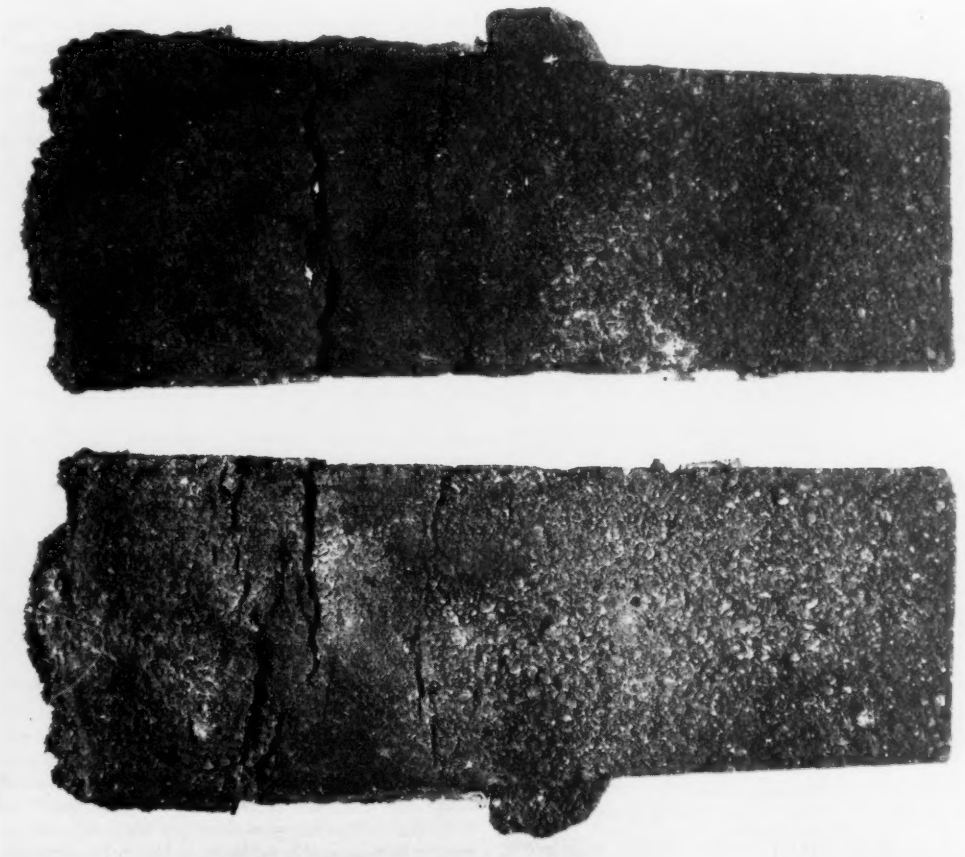


Fig. 15—Sections of intermediate red brick sample taken from 'B' furnace, Steel, Peech and Tozer, at the end of the 7th campaign

Table VIII

REFRACTORINESS-UNDER-LOAD TESTS ON USED BRICK ZONES

Load 28 lb/in²; Temperature maintained at 1600° C

Brick	Zone	Results
Green 9A	Silicate (1–2 in. from hot face)	Failed 1560° C
Brown 18C	½–1½ in. from hot face	(1) Failed 48 min at 1600° C (2) Failed 11 min at 1600° C
Blue 13A	Silicate zone (2 in. from hot face)	Failed 1570° C
Yellow 11A	Silicate zone (2 in. from hot face)	Failed 1600° C
Bilston yellow magnesite-chrome brick	Hot face	0·12% deformation after 1 h at 1600° C
	Silicate zone (3 in. from hot face	0·46% deformation after 1 h at 1600° C
	Cold end	Sheared after 30 min at 1600° C

being chosen to coincide with the changes in texture that occurred along the length of the brick. The results are as follows.

Chemical Analyses and Percentage Apparent Porosity

Zone No.	1	2	3	4	5
Distance from working face, in.	0–1	1–2¼ (crack)	2¼–3½	3½–4¾	6½–7½ (cold end)
Porosity, %	24·8	17·9	17·3	23·2	23·7
SiO_2, %	4·90	7·70	7·72	5·64	5·64
TiO_2, %	0·18	0·16	0·15	0·16	0·17
Al_2O_3, %	11·59	13·23	11·63	13·28	12·99
Fe_2O_3, %	24·26	10·86	10·82	11·81	11·40
CaO, %	3·92	4·48	5·32	2·35	1·90
MgO, %	34·00	39·66	40·00	40·44	40·82
MnO, %	0·60	0·42	0·30	0·12	0·05
Cr_2O_3, %	19·97	22·97	23·46	23·35	26·49
Loss, %	0·12	0·12	0·38	0·54	0·42

X-ray and Petrographic Examinations

X-ray powder photographs were taken, a 9-cm camera being used with filtered manganese radiation. The crystalline phases identified were:

Distance of sample from hot face, in.	*Crystalline phases identified*
0 (hot face)	(1) A spinel rich in iron oxide, cell size 8·34Å
	(2) Much smaller amount of another spinel containing less iron oxide
½ in.	(1) Magnesia
	(2) A spinel (cell size 8·26Å)—iron oxide solid solution
	(3) Monticellite
1¾ in.	(1) Magnesia
	(2) A spinel of the same cell size as that in the unused brick, i.e. 8·24Å
	(3) Monticellite
	(4) Forsterite
4¼ in.	(1) Magnesia
	(2) A spinel (as in unused brick)
	(3) Forsterite
	(4) A small amount of monticellite
5¼ in.	(1) Magnesia
	(2) A spinel (as in unused brick)
	(3) Forsterite
	(4) A small amount of monticellite

Thin sections have been examined of samples covering the 3 in. behind the hot face, including both sides of the large crack. The chromite grains at the hot face showed some iron oxide penetration, but the grains further away from the hot face had remained transparent. The magnesia, on the other hand, had picked up iron oxide and was now opaque; the original rounded aggregations of periclase had been broken up. It is probable that a spinel solid solution between magnesio-ferrite and magnetite, on the one hand, and chromite, on the other hand, has been formed because some of the opaque magnesia grains were firmly attached to the iron-oxide-penetrated chromite grains.

Monticellite, with some unchanged forsterite, were the main silicate minerals, but at the hot face a little tricalcium silicate was possibly present. The brick was porous at the hot face but towards the crack it became denser owing to the interstices between the magnesia and the chromite grains being filled with monticellite and some forsterite.

Beyond the crack the porosity showed a further increase and the magnesia became transparent while the amount of monticellite gradually decreased.

Observations

The results showed that lime and silica had both penetrated for about 3½ in. behind the hot face, but the iron oxide had concentrated within 1 in. behind the hot face. The brick had not developed a dense hot face, the small decrease in porosity behind the hot face having been caused by the concentration of monticellite. The magnesia at the hot face had absorbed iron oxide and formed magnesio-ferrite. This spinel had then entered into solid solution with the chromite and probably magnetite. The crack appeared to have formed within that portion of the brick which had been penetrated by lime and silica.

Samples taken from the 1st Roof at Ijmuiden

These samples were taken from the centre and towards the front of each of the five panels. Each brick had a slightly fused surface: they were all cracked parallel to the working face and zones of different texture and density were apparent along the length of each sample. The chemical and mineralogical composition of the zones and their percentage apparent porosity were determined. The chemical analysis figures showed that the lime and silica contents reached a maximum in the second or third zone 1–2 in. behind the hot face and this effect, as well as the concentration of iron oxide in the first zone, is shown graphically in Fig. 16. The graphs were made by plotting the percentage analysis figures of each zone at the point half-way along the zone. The positions of cracks, the total length of the samples, and the percentage apparent porosity of the zone specimens are also recorded on the graphs.

Samples taken from the 4th Trial Roof at Consett

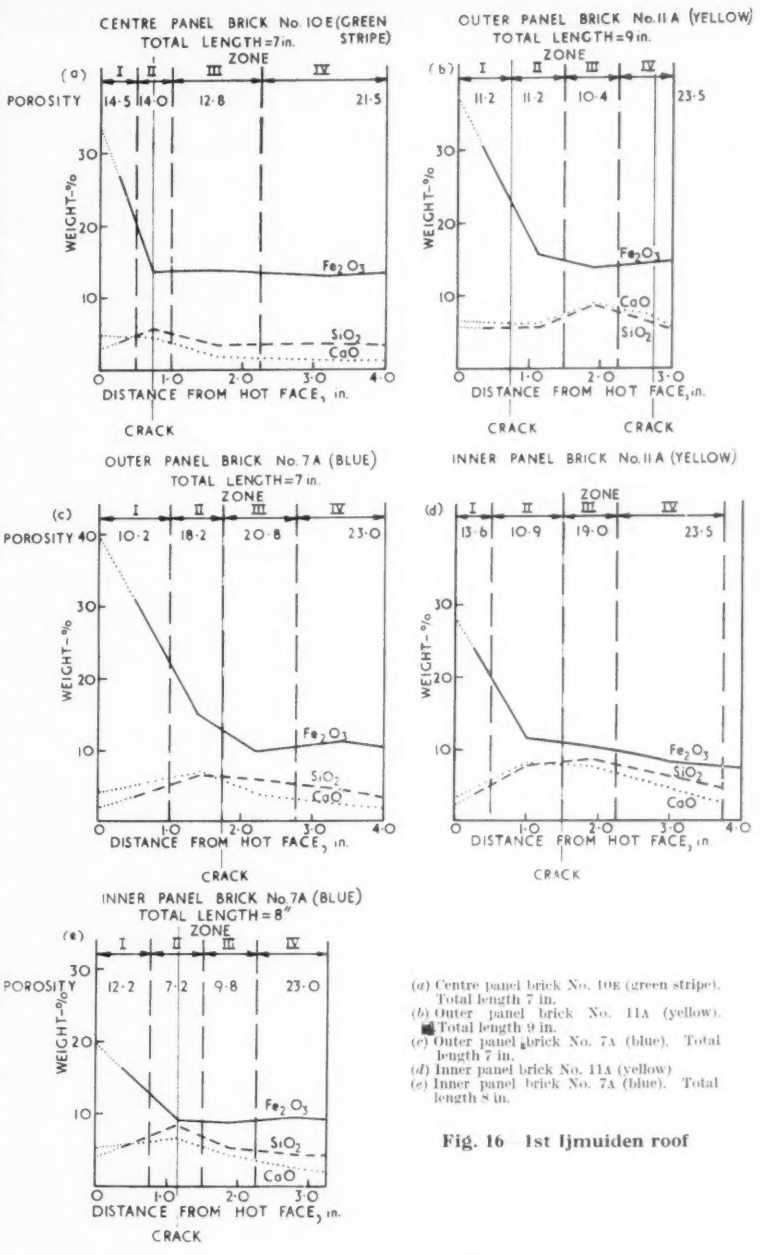
The samples were taken from the centre and the two adjacent panels in the roofs; the green chrome-magnesite brick from the inner panel held a hard but not fused surface layer, but both orange and yellow magnesite-chrome brick samples were fused at the hot face. The samples were cut into sections parallel to the hot face, the position of the cuts corresponding to positions where the texture appeared to change, but often it was convenient to make a crack the boundary of a section or zone. The results of the chemical

analysis and porosity determinations are given graphically in Fig. 17.

Samples taken from Roof 3, 'B' Furnace, Steel, Peech and Tozer

Two sample bricks were examined, one taken from each of the left-hand end panels, the outer panel of green bricks, and the inner panel of brown bricks. These were both rib bricks and the surface layer of each brick was open-textured, 'dry', and contained many shiny black crystals. Results are shown graphically in Fig. 18.

These results and those obtained from the previous samples all show that lime and silica have concentrated behind the working face, but that the iron oxide content does not reach a maximum value behind the hot face; absorbed iron oxide is confined to the first 1 in. of the brick, and its maximum amount is at the hot face. The position of the crack or cracks in the samples is not consistent or directly related to the positions of maximum lime and silica contents. Although the bricks in the roof slab from time to time and the actual time the sample brick last lost an inch or two from its surface is not known, this unknown factor must have an important bearing on both the position of the crack and the chemical analyses of the various zones in the chosen samples. Since it was shown by the experiments in the panel spalling test that unused bricks cracked behind the hot face, even without addition of iron oxide or the absorption of fluxes, the lack of relationship between flux penetration and crack position is not surprising.

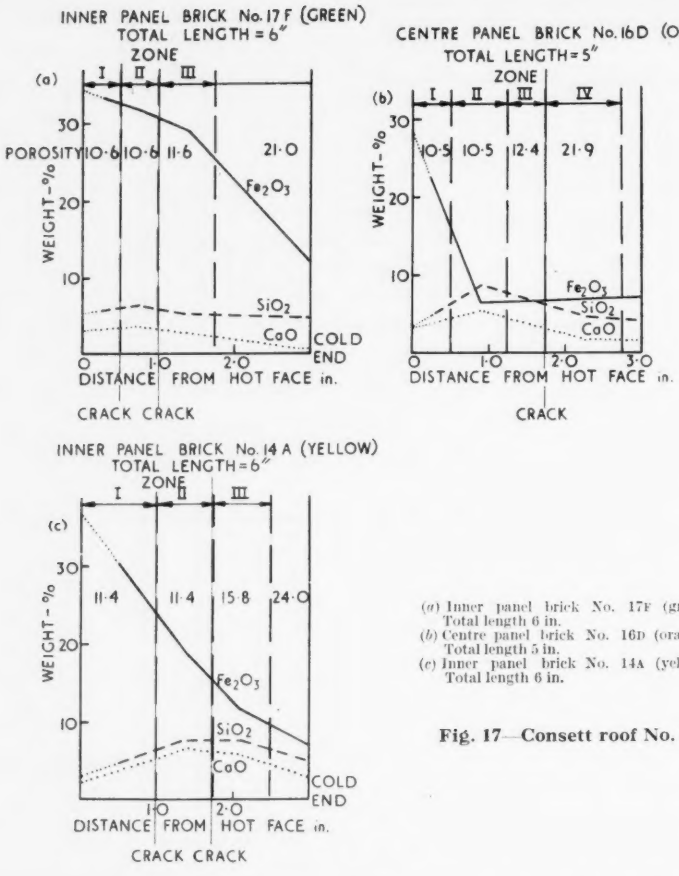


(*a*) Centre panel brick No. 10E (green stripe). Total length 7 in.
(*b*) Outer panel brick No. 11A (yellow). Total length 9 in.
(*c*) Outer panel brick No. 7A (blue). Total length 7 in.
(*d*) Inner panel brick No. 11A (yellow)
(*e*) Inner panel brick No. 7A (blue). Total length 8 in.

Fig. 16—1st Ijmuiden roof

General Conclusions from X-Ray and Petrographic Examination

Over 100 X-ray powder photographs have been taken and at least 60 thin sections have been examined under the microscope. The results of the examination of specimens taken from the panelled roofs agree with the result given in the sub-section on the used red brick. The X-ray photographs have shown that in every case the mineral concentrated behind the hot face is monticellite ($MgO.CaO.SiO_2$). The lime and silica have penetrated into the brick and have combined with forsterite and magnesia, the ratio of lime to silica content being such that monticellite has formed. The cell size determination of the spinel phases present in the various zones confirm that the iron oxide was generally limited to zone 1 and the blurred nature of the spinel X-ray reflections indicated that the solid-solution formation of the penetrated iron oxide with the chrome grain was incomplete. The petrological examination confirmed the X-ray results but also showed interesting features of the



(*a*) Inner panel brick No. 17F (green). Total length 6 in.
(*b*) Centre panel brick No. 16D (orange). Total length 5 in.
(*c*) Inner panel brick No. 14A (yellow). Total length 6 in.

Fig. 17—Consett roof No. 4

penetration of iron oxide, lime, and silica on the resultant brick structure.

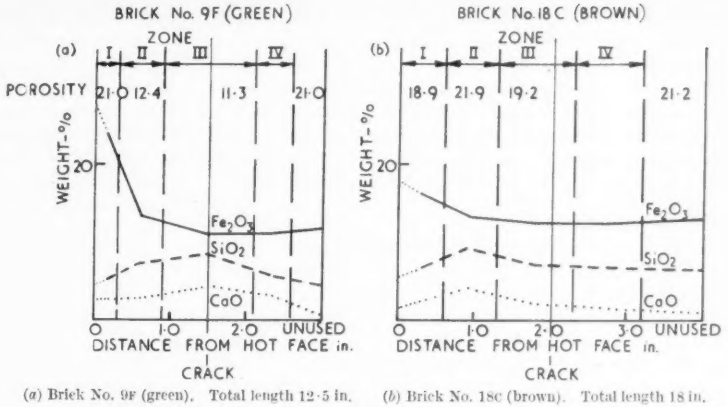
Most of the basic bricks appear very open-textured in thin section. Seldom is there any extensive and continuous bond between the coarse chromite and magnesia and the remainder. In a large number of specimens, particularly those with a low silicate content, the large chromite crystals are usually surrounded by voids. Where good bonding does occur it is usually silicate derived from the chrome ore gangue, in which case forsterite envelopes are formed around the chrome grains attaching them to the matrix. In bricks of high silicate content, however, large rather isolated areas of silicate can often be observed and the direct MgO–chromite bond is rarely found, but this type is probably a spinel bond. A good example is seen in striped green bricks, which have a low silicate content and a high iron content in the magnesia.

The alteration and zoning in used bricks follows the same general pattern. At the hot face the original brick structure has completely disappeared. Chrome grains, some parts of which may still be transparent, show iron oxide penetration from those edges nearest the hot face. This penetration is seen more clearly in chrome grains further away from the hot face—the ' hot ' edge of the chrome absorbs iron in preference to the ' cold ' edge. The magnesia is usually completely altered into large opaque crystals with magnesio-ferrite, magnetite, and magnesio-chromite solid solution inclusions. These magnesia–spinel complexes are sometimes firmly attached to the ' hot ' edges of chrome grains. The silicate content at the hot face is normally fairly low, and usually trapped in front of chromite grains. In most cases it is monticellite, but merwinite or a pyroxene might be present in small amounts at the hot face and the iron oxide does not penetrate further than 1 in. from the hot face. Beyond this point the monticellite increases and the porosity decreases to a minimum at about 2 in. behind the hot face.

Lime and silica from the furnace react with the forsterite and magnesia to form monticellite, the chromite being relatively inert. Since this is a low-melting-point compound it moves from hotter parts of the brick down the temperature gradient. Where the bond of the original brick was forsterite, one can observe all stages of its conversion to monticellite. Where the silicate content is low the movement is via the voids in the matrix and around the chromite grains. In both cases the result is the same: the bond becomes monticellite.

The appearance of the bricks in the Bilston ' A ' roof is quite different from those—even the same brand—taken from the panel roofs, although they did crack parallel to the hot face. Small pieces of brick taken from the surface of the Bilston roof show that this trial roof has behaved in the same way as the previous roof. Samples taken during and at the end of the previous campaign were carefully tested and examined and results have been reported.[7] The mineralogical composition of these samples shows marked differences from the results reported above. Iron oxide, lime, and silica penetrated the bricks in both cases but the ratio of lime to silica was much greater in the case of the Bilston bricks, even after 633 heats. The iron oxide penetration of the hot face had caused the magnesia to grow into long crystals, perpendicular to the hot face, which were surrounded with a magnetite and magnesio-ferrite solid solution that had dissolved the chrome grains. This surface layer was a black dense mass very low in lime and silica. The lime and silica had concentrated about 3 in. behind the working surface in the form of di- or tri-calcium silicate, the lime/silicate ratio being too great for the formation of the lower

melting-point monticellite in this zone. This difference in chemical and mineralogical composition is reflected in creep and load tests on the brick zones. The presence of an increased monticellite content causes a reduction in the load-bearing capacity of the samples, but the presence of di- or tri-calcium silicate (high-melting-point compounds) produces samples of greater load-bearing capacity than those of the original brick. Some results are shown in Table VIII. These experiments were made with small cylindrical test-pieces 1 in. tall and 1 in. dia.



(*a*) Brick No. 9F (green). Total length 12·5 in. (*b*) Brick No. 18C (brown). Total length 18 in.

Fig. 18—Steel, Peech and Tozer 'B' furnace, roof No. 9

The Bilston samples had been in the roof for a much longer time than had those taken from the other roofs, and the pick-up of lime during this longer period and its subsequent migration behind the face had caused this marked difference in the lime/silica ratio. The iron oxide pick-up would also be greater in the Bilston samples but, whereas the loss of the hot face from time to time would result in the loss of the major part of the iron oxide, the lime would be retained continually behind the hot face.

Section 6—SUMMARY

Design and Operation

The results of these co-operative trials show that the design and operation of an all-basic furnace have a far greater influence on the life obtained than have observed differences in brick quality. The yellow magnesite-chrome brick which gave such outstanding performance (1989 casts) at Bilston was the same brand and had very similar properties as the yellow magnesite-chrome bricks that gave lives of 275, 179, and 213 casts at the other three plants. It is considered that the attempts made at Bilston to minimize movement of the roof bricks and maintain a limited temperature variation (1680–1600° C) for the most of the campaign are factors of paramount importance.

Brick Quality

In spite of the dominance of these operational and design factors, and although the information gained from the trials does not justify the placing of the bricks in a definite order of merit, it is possible to draw certain conclusions on brick quality from the trial results. At Consett the green chrome-magnesite brick gave a better performance than the yellow and orange magnesite-chrome bricks, and the green and blue bricks, which were both chrome-magnesite, were considered to give about equal performance in the following campaign. The green brick is characterized by its high volume stability at 1700° C and its superior refractoriness-under-load value, but the blue brick has a similar bursting expansion and less volume stability.

At Ijmuiden there was no great difference between the residual thicknesses of the various bricks; here the yellow magnesite-chrome brick was no better than the blue chrome-magnesite, but the green chrome-magnesite brick was slightly better than the brown chrome-magnesite brick. Striped green chrome-magnesite bricks have been used in the centre panel because experience has shown that these bricks usually give better life than other brands. These green and striped green chrome-magnesite bricks all show good volume stability at 1700° C and good refractoriness-under-load values, but their iron oxide bursting tendency is not particularly low. Green chrome-magnesite brick was considered to be slightly better than brown and red chrome-magnesite bricks in 'B' furnace at Steel, Peech and Tozer. In 'F' furnace the blue chrome-magnesite brick was at least equal to the yellow magnesite-chrome brick; this confirmed the results of the comparison of magnesite-chrome and chrome-magnesite bricks at the other plants.

These results indicate that *volume stability at 1700° C and good refractoriness-under-load values or low creep rate are important properties*, but that the iron oxide bursting index is not a critical property in the determination of high durability. Indeed, it has been tentatively suggested that a volume shrinkage at 1700° C may be balanced by a rather higher, though still reasonable, iron oxide burst to produce a volume-stable roof brick. It should be realized, however, that all the trial roof bricks gave low iron oxide bursting indices compared with ordinary-quality chrome-magnesite bricks, and a really high bursting tendency might still therefore prove detrimental in a roof brick.

The roof bricks all failed by the slabbing of the surface, and resistance to thermal shock is therefore a desirable property. Most of the bricks passed the standard laboratory prism spalling test, but all the bricks had cracked after being subjected to six heating cycles in the panel test-rig. It must be assumed, therefore, that the bricks in the panel roof trials were cracked at an early stage in each campaign. Any factor, whether it be increased thermal shock resistance in the brick or improved construction or change of furnace operation, which tends to delay crack

formation or keep the cracked end in position in the roof, may be a determining factor in roof life.

Consideration of the other data suggests that apparent porosity and crushing strength, and magnesia-chrome ratio within at least the range of values studied, are not so important in determining roof life as thermal shock resistance, volume stability, and good load-bearing capacity at high temperature.

Future Developments

The Committee feels that work of the type described has been of real value and has achieved a substantial clarification of existing ideas on brick quality. The development of the all-basic furnace can best be forwarded by the study of further trial roofs, but it can be speeded up by recourse to pilot-scale work, where new (and possibly risky) ideas, including tests at abnormally high temperatures, can be tried out more quickly and safely than on production furnaces. The panel spalling test unit at the British Ceramic Research Association has already suggested a number of possible lines of improvement, whilst the larger all-basic furnace test-rig of the United Steel Cos., Ltd., should offer the possibility of trying out not only new materials but also the effect of changes in design and operating conditions. The effect of changes in design on the stress distribution in the roof is continually being studied on the B.I.S.R.A. Perspex model. With such equipment it should be possible to test radically new ideas and materials and only recommend large-scale trials on those whose performance in the rig is particularly promising.

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Graphite Electrode Consumption in Electric-arc Furnaces

A STATISTICAL ANALYSIS

By T. A. Cosh, B.Sc., A.R.T.C., F.I.M.

SYNOPSIS

Data relating to electrode consumption in production-type electric-arc furnaces have been subjected to statistical analysis. From an analysis of these data indications are given of the extent to which electrode length, diameter, and surface area influence electrode consumption. The effect of electrode diameter on electrical consumption has also been analysed.

It has been concluded that a reduction of the surface area of electrodes exposed in the furnace, made by using electrodes of smaller diameter, is effective in reducing both electrode consumption and electrical consumption. 1280

Introduction

ALTHOUGH much has been said regarding the consumption of electrodes in electric-arc furnaces, there has been a singular lack of published information from current practice to support views one way or another. Published papers[1, 2] have emphasized the importance of the electrical resistivity of electrodes. Without doubt the resistivity will distinguish a bad electrode from a good one and abnormal resistivity may account for periodic variations in electrode consumption within a furnace. Resistivity cannot, however, account for the wide variations in electrode consumption between different furnaces. In the course of the discussion[3] of one of the above-mentioned papers[1] it was stated by Wood, and generally agreed to by others, that there were other factors, more important than resistivity, to account for variations in electrode consumption, but no data in support of these statements were given.

The present paper is based upon data provided by members of the Refractories Panel of the British Steel Castings Research Association. These data, subjected to statistical analysis, provide some interesting

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Mr. Cosh is Head of the Steelmaking Section of the British Steel Castings Research Association.

Table I
SUPPLIED AND DERIVED DATA FOR 18 FURNACES SURVEYED

Furnace	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Electrode Dia., in.	12	14	10	10	8	8	14	8	10	10	10	8	9	6	8	8	8	6
Electrode Consumption, lb/ton Steel	17·8	20·95	15·1	15·2	10	10	17	16·51	11/13·5	14·5	12·5	13·5	18	22	9	9·6	6·4	5·7
Electrical Consumption, kW/ton Steel	807	837	720	710	706	706	700	871	620	720	670	950	860	900	670	567	520	500
Electrode Surface Area, in²	5559	6162	4554	4794	3300	3300	7122	2955	3624	3444	2874	2730	4269	1524	2730	3240	3180	1560
Electrode Length, in.	46	44	44½	48	41½	41½	52	37	36	34	28	34	48	25½	34	41	40	25
Max. Current Density, A/in²	88	61	133	133	72	72	85	90	153	67	35	103	99	89	94·5	160	125	158
Power-on to Tap Time, h	5	4·5	4·3	4·3	5	5	5·25	2·3	2·0	3	3·75	2·63	3	3	2·42	2·17	1·17	1·33
Operating Capacity, tons	10–12	7–11	10	10·5	10	10	18–20	1·5–2·5	5·0	4·5	4·5	2·5–3	4–7	2	3·6	4	3·55	3
Operating Rate, tons/h	2·2	2·0	2·3	2·4	2	2	3·6	0·87	2·5	1·5	1·2	1·05	1·8	0·67	1·48	1·84	2·85	2·45

information on an important and perplexing aspect of electric-arc furnace steelmaking practice.

THE FURNACES SURVEYED

The survey covers a total of 18 furnaces, all using graphite electrodes. The data supplied and derived concerning these furnaces and relevant to electrode consumption are given in Table I. Of the eighteen, all but furnaces *Q* and *R* operate on a basic lining. All the furnaces are used in the production of fully killed plain carbon and alloy steel for castings, the average quality being similar in all cases. The transformer ratings and voltage tappings vary from furnace to furnace; no data are available on either actual current or voltage settings used, since both these vary considerably in practice, even between different heats of similar quality steel made in any one furnace. Current density data are based, therefore, on the maximum possible current from the transformer in use.

In the main, the data may be said to relate to a heterogeneous set of furnaces, varying as they do in operating capacity from 1½ to 20 tons. Six of the furnaces (*A*, *B*, *C*, *D*, *E*, *F*) conform to an operating capacity of approximately 10 tons and reasonably close limits of operating rate; these six furnaces have therefore been considered to be of the same class for comparison purposes, and the analysis is mainly based on the data relating to these six furnaces. Similar data relating to all 18 furnaces, however, are included in Table I for information. The electrode consumption figures in Table I include losses due to breakages and consumption of jointing nipples as well as that of actual electrodes, based on the weight of metal tapped.

ELECTRODE CONSUMPTION AND SURFACE AREA

A preliminary analysis indicated that the best correlation appeared to exist between electrode consumption (lb/ton) and the surface area of electrode (in²) within the furnace. While the plot of these two variables for the 18 furnaces (Fig. 1) appears to have a large amount of scatter, the calculated coefficient of correlation ($r = +0{\cdot}66$) is of a high degree, and for the number of furnaces concerned is, statistically, very significant. A similar plot for the six 10-ton furnaces (Fig. 2) shows an even higher degree of correlation ($r = +0{\cdot}997$) and a very significant one even for the small number of furnaces to which the correlation pertains, sufficiently significant as to be well nigh independent of any other factor.

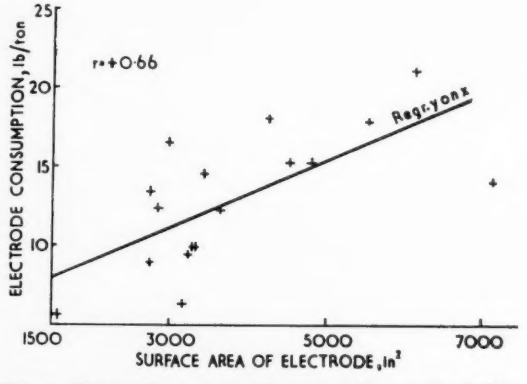

Fig. 1—Electrode consumption *v.* surface area of electrode (18 furnaces)

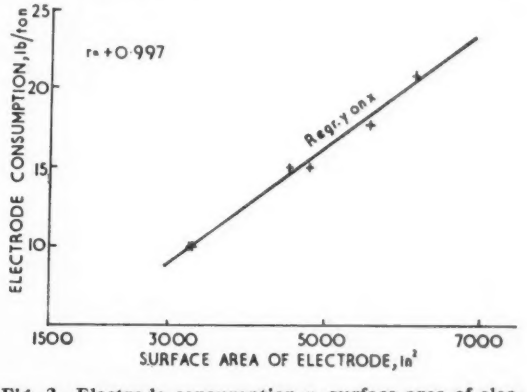

Fig. 2—Electrode consumption *v.* surface area of electrode (6 furnaces)

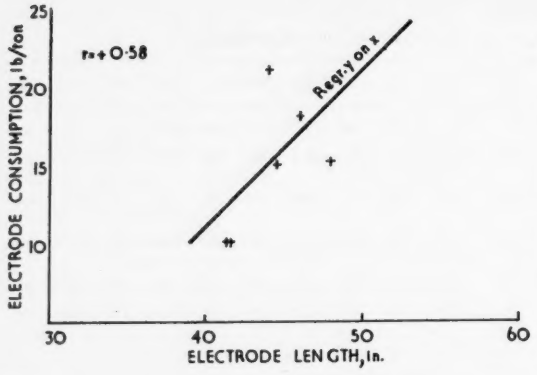

Fig. 3—Electrode consumption *v.* electrode length (6 furnaces)

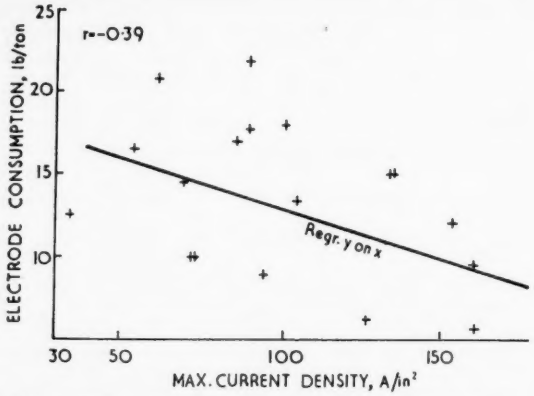

Fig. 5—Electrode consumption *v.* maximum current density (18 furnaces)

The surface area may be reduced by either a reduction in electrode length or a reduction in electrode diameter. Statistically, the electrode length (Fig. 3) shows a lesser degree of correlation with electrode consumption than does electrode diameter (Fig. 4). A reduction in electrode length would decrease the electrical resistance, which would be increased by a reduction of the electrode diameter. Any alteration to the electrode length would involve a change in the fundamental design of the furnace. A lowering of the roof would be required with the possibility of thereby adversely affecting roof refractory wear. A reduction of electrode diameter will, of course, increase the current density. Unfortunately the six 10-ton furnaces have such a diversity of current ratings as to give no correlation when related to electrode consumption. However, when related to the electrode consumption for the 18 furnaces, the current density (Fig. 5) shows a slight trend in favour of an increased current density. The coefficient of correlation for this plot ($r = -0{\cdot}39$) is poor in statistical significance and its chief merit is that it is in fact negative, indicating that as the current density increases, the electrode consumption decreases. The value of $r = -0{\cdot}39$ is in close agreement with a previously published correlation[3] for electric-arc furnaces. Of course, the current density must not exceed the limiting maximum value for the size of electrode concerned.

POWER CONSUMPTION

From the correlation between power consumption and electrode consumption (Fig. 6) and that between power consumption and electrode diameter (Fig. 7), it would appear that not only does a reduction in electrode diameter and, hence, surface area imply a reduction in electrode consumption, but also that this reduction should be accompanied by a reduction in power consumption.

Trials carried out by McCafferty,[5] with 14-in. dia. and 12-in. dia. electrodes in periods of 8 weeks, led him to conclude that, while the smaller electrode gave a reduction in electrode consumption, this was accompanied by an increase in power consumption. It will be observed from the results of these trials, shown in Table II and Table III, that the ingot yield per heat rate is higher for the period when 12-in. dia. electrodes were in use by 0·6 ingot tons per heat. An analysis of the ingot yield per heat rate and power consumption data from Table III, given in Fig. 8, indicates that the power consumption increase is attributable to an

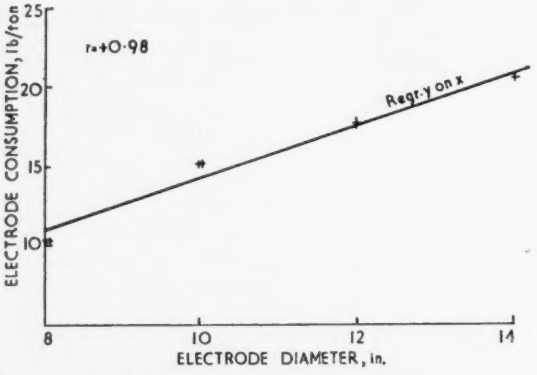

Fig. 4—Electrode consumption *v.* electrode diameter (6 furnaces)

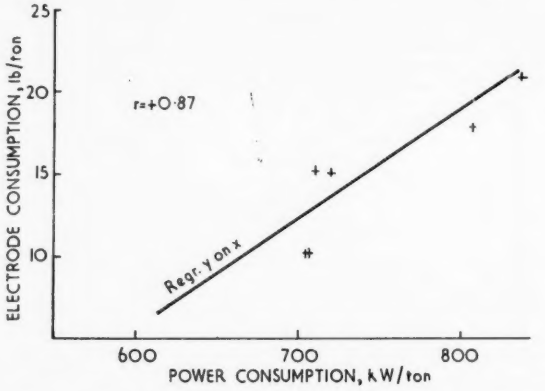

Fig. 6—Electrode consumption *v.* power consumption (6 furnaces)

Table II

TRIALS WITH 14-in. ELECTRODES AT WM. BEARDMORE AND CO., LTD.

From McCafferty[5]

Week Ending	No. of Heats	Ingot Yield, tons	Power Consumption, kWh/ton	Carbon per ton, lb
6/6/53	20	327	748	20
13/6/53	19	339	723	21
20/6/53	19	339	715	18
27/6/53	19	317	740	24
4/7/53	20	360	601	17
11/7/53	20	349	705	19
15/8/53	19	337	692	21
22/8/53	19	324	707	18
Averages	19·4	336·5	704	19·75

increase in ingot yield rate. It is probable that, for comparable yield rates, not only would the electrode consumption decrease with 12-in. dia. electrodes as against 14-in. dia. electrodes, but also that (i) the decrease would be greater than that indicated by McCafferty and (ii) the power consumption would decrease. It should be noted that the data in Tables II and III do not include losses due to breakage.

Further analysis of McCafferty's data (Fig. 9) indicates that when using one size of electrode (12 in. dia.) the power consumption increases as the electrode consumption decreases.* The correlation of the data on this point is not very great but there is that trend. Houseman[6] has confirmed this finding but has indicated that, in terms of relative cost, the saving from decreased electrode consumption is much greater than the increase from additional power consumption.

A summary of the analyses illustrated in Figs. 1–9 is given in Table IV.

OPERATION RATE

Short power-on to tap times favour acid steel practice, as can readily be gauged from the low electrode consumption figures of furnace Q (6·4 lb/ton) and furnace R (5·7 lb/ton). It should be noted in respect of these two furnaces that furnace Q with the higher melting rate has the higher electrode consumption, but that it used 8-in. dia. electrodes as against the 6-in. dia. of furnace R. There are, however, insufficient data available to analyse the full extent of the influence of operating rate on electrode consumption.

* The apparent contradiction between Figs. 6 and 9 is due to the fact that whereas the former relates to electrodes of differing diameters, the latter relates only to electrodes of a constant diameter (12 in.).

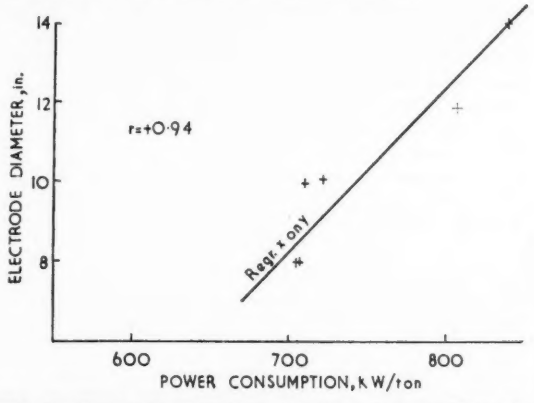

Fig. 7—Electrode diameter *v.* power consumption (6 furnaces)

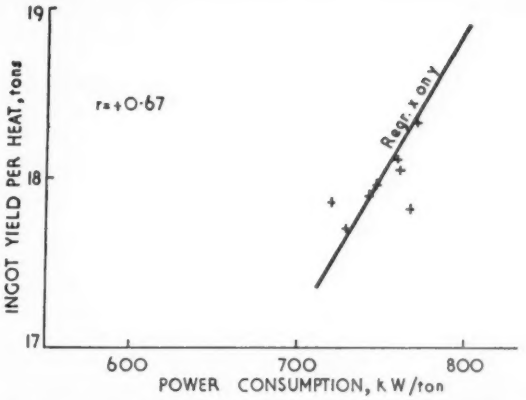

Fig. 8—Ingot yield per heat *v.* power consumption. Beardmore furnace, 12-in. dia. electrodes. Analysis of data by McCafferty

CONCLUSIONS

The analysis shows that, for the size range of furnaces considered and for a given melting rate:

(1) The electrode consumption is closely related to the electrode surface area within the furnace in such a way that a reduction in the surface area is effective in producing a reduction in the electrode consumption.

(2) The reduction of surface area should be made by reducing the diameter rather than the length of the electrodes.

(3) An indication of the decrease in electrode consumption which may be anticipated by such a reduction in diameter can be calculated from the appropriate regression equation.

(4) The electrode diameter, however, should not

Table III

TRIALS WITH 12-in. ELECTRODES AT WM. BEARDMORE AND CO., LTD.

From McCafferty[5]

Week Ending	No. of Heats	Ingot Yield, tons	Power Consumption, kWh/ton	Carbon per ton, lb
5/6/54	19	339	719	18
12/6/54	19	340	742	17·8
19/6/54	19	341	745	17
26/6/54	20	354	728	18
3/7/54	18	325	759	18
14/8/54	18	321	766	15
21/8/54	19	344	759	18
28/8/54	19	349	768	17
Averages	18·9	339·1	748	17·35

Table IV

SUMMARY OF STATISTICAL ANALYSIS OF DATA SHOWN IN FIGS. 1–9

Graph Fig. No.	Co-ordinates	No. of Samples	Correlation Coefficient (r)	Regression Equation	Standard Error	Significance Level, % Probability	Statistical Value of Correlation
1	x Electrode Surface Area y Electrode Consumption	18	+0·66	— $y = 0{\cdot}00211x + 4{\cdot}78$	— 3·4	< 0·1%	Very significant
2	x Electrode Surface Area y Electrode Consumption	6	+0·997	— $y = 0{\cdot}00367x - 2$	— 0·30	< 0·1%	Very significant
3	x Electrode Length y Electrode Consumption	6	+0·58	— $y = 0{\cdot}99x - 29$	— 3·2	2%	Significant
4	x Electrode Diameter y Electrode Consumption	6	+0·98	— $y = 1{\cdot}818x - 3{\cdot}94$	— 0·64	< 0·1%	Very significant
5	x Max. Current Density y Electrode Consumption	18	−0·39	— $y = 0{\cdot}05x - 18{\cdot}6$	— 4·1	10%	Trend
6	x Power Consumption y Electrode Consumption	6	+0·87	— $y = 0{\cdot}674x - 34{\cdot}7$	— 1·9	3%	Significant
7	x Power Consumption y Electrode Diameter	6	+0·94	$x = 23{\cdot}6y + 503$ —	18·5 —	< 0·1%	Very significant
8	x Power Consumption y Ingot Yield per Heat	8	+0·67	$x = 55{\cdot}7y - 255$ —	12·4 —	7%	Trend
9	x Power Consumption y Electrode Consumption	8	−0·52	— $y = 0{\cdot}03x + 40$	— 1·36	>10%	Trend

be reduced to less than the limit imposed by considerations of maximum current density. There are indications that, within the limit of maximum current density, the increase in current density arising from a reduction in the electrode diameter will not adversely affect electrode consumption.

(5) A reduction in the power consumption is shown to result from the use of electrodes of smaller diameter; however, for a given diameter of electrode, the power consumption may increase as the electrode consumption is decreased.

(6) The high production rates of acid steel practice indicate a lower electrode consumption rate than can be obtained with the longer power-on to tap times of basic practice.

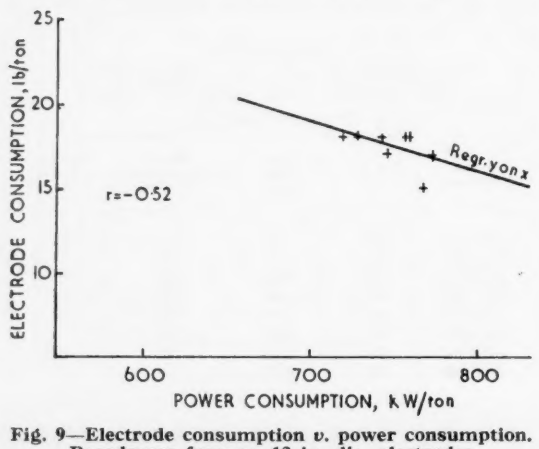

Fig. 9—Electrode consumption *v.* power consumption. Beardmore furnace, 12-in. dia. electrodes

Acknowledgments

Acknowledgment is made to the following member firms of the B.S.C.R.A. who through the Association's Refractories Panel contributed the information contained in Table I: Edgar Allen and Co., Ltd., Wm. Beardmore and Co., Ltd., The Clyde Alloy Steel Co., Ltd., The English Steel Corporation Ltd., K and L Steelfounders and Engineers Ltd., F. H. Lloyd and Co., Ltd., Osborn Foundry and Engineering Co., Ltd. Wm. Beardmore and Co., Ltd. also made available to the author the data included in Tables II and III, which had previously been submitted to the Steelmaking Division of the B.I.S.R.A.

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Templeborough
Melting Shop Reconstruction Scheme

By F. Moore

SYNOPSIS

Fourteen O.H. furnaces of 80 tons' capacity were each converted to 100 tons' capacity. This involved a complete change of the structures and equipment needed for casting. The ways in which the changes were made to minimize production losses are described.

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TEMPLEBOROUGH MELTING SHOP is the largest cold-charged shop in Europe and, before the changes described in this paper, it housed 14 O.H. furnaces each of 80 tons' capacity. It has been in operation more than 35 years and originally consisted of 60-ton units. The ever-increasing need for high productivity made it necessary to enlarge the furnaces within the limits imposed by the size of the building, and eventually it was decided to increase the capacity of each furnace to 100 tons.

The reconstruction was planned in three stages:

(i) To design and install the 100-ton furnaces
(ii) To provide adequate facilities for charging the enlarged units
(iii) To provide facilities to dispose of the increased output and higher slag volume.

Item (iii) proved to be the most difficult problem and is the subject with which this paper is chiefly concerned.

THE PROJECT

Preliminary consideration of the project showed that certain requirements were necessary. These were :

1. Larger ladles to deal with the increased quantities of metal and slag

2. Ladle cranes of greater capacity to handle larger tonnages and heavier ladles

3. New crane girders, as larger cranes would stress the existing track girders beyond permissible limits

4. Investigation of existing building and crane track stanchions to see if they could support increased loads. Stresses under the new conditions were:

(i) *Columns adjacent to mould shop*	tons/in²
Permissible stress:	7·18
Axial compressive stress:	3·9
Bending stress:	1·54
(ii) *Centre columns*	tons/in²
Permissible stress:	6·86
Axial compressive stress:	4·42
Bending stress:	2·0

5. Investigation of foundations to the stanchions to see if they could support the increased loads. The maximum bearing pressure on the earth under the new conditions was:

(i) 3·35 tons/ft² on columns adjacent to the mould shop
(ii) 2·51 tons/ft² on centre columns.

6. Investigation of existing electrical supply to see if it was adequate for the new ladle cranes. It was found necessary to supplement the capacity of the feeder cables to the track conductors to provide for the increased load, and to allow division of track conductors into sections without an excessive drop in voltage.

7. Necessity to carry out reconstruction without impeding production, and phase this to coincide with installation of the larger furnaces.

The need for timing the ladle crane erection with the erection of larger furnaces was important for four reasons:

(i) To obtain the increased output as soon as possible
(ii) While the new ladle cranes could handle 80 and 100 tons' capacity ladles, it was impossible for the old ladle cranes to pick up a large ladle. Therefore, two new ladle cranes had to be brought into use simultaneously, so that if either mechanical or electrical faults occurred, another crane of that capacity would be available
(iii) The placing of two extra cranes on the crane track would cause congestion, and it was important to remove two old cranes as soon as the new cranes were ' run in,' and the crane drivers had become accustomed to the feel of the cranes
(iv) Congestion was not confined to the crane track. Changing from 80 to 100 tons' capacity ladles involved keeping suitable numbers of both sizes of ladles in service. This increased the number in use, whilst the relative numbers of each type changed as each 100-ton furnace came into use. Here the pit management had to be particularly careful to see that enough of the bigger ladles were available as each of the larger furnaces became ready for use.

Safety

When work is carried out in plant where hot metal is being handled continuously, the safety of engineering and melting shop personnel is of paramount importance.

Special precautions were needed to ensure that the work would be done without an accident and the melting-shop management, safety officer, and engineering department drew up special safety regulations which were to be observed when erection work was proceeding. During the reconstruction of the track there was only one accident.

Planning

Complete planning of all stages was necessary before work began. The production management could then be told when inconveniences would occur and when they might expect to have new plant

Paper received 27th January, 1956.
Mr. Moore is Deputy Mechanical Maintenance Superintendent with Steel, Peech and Tozer.

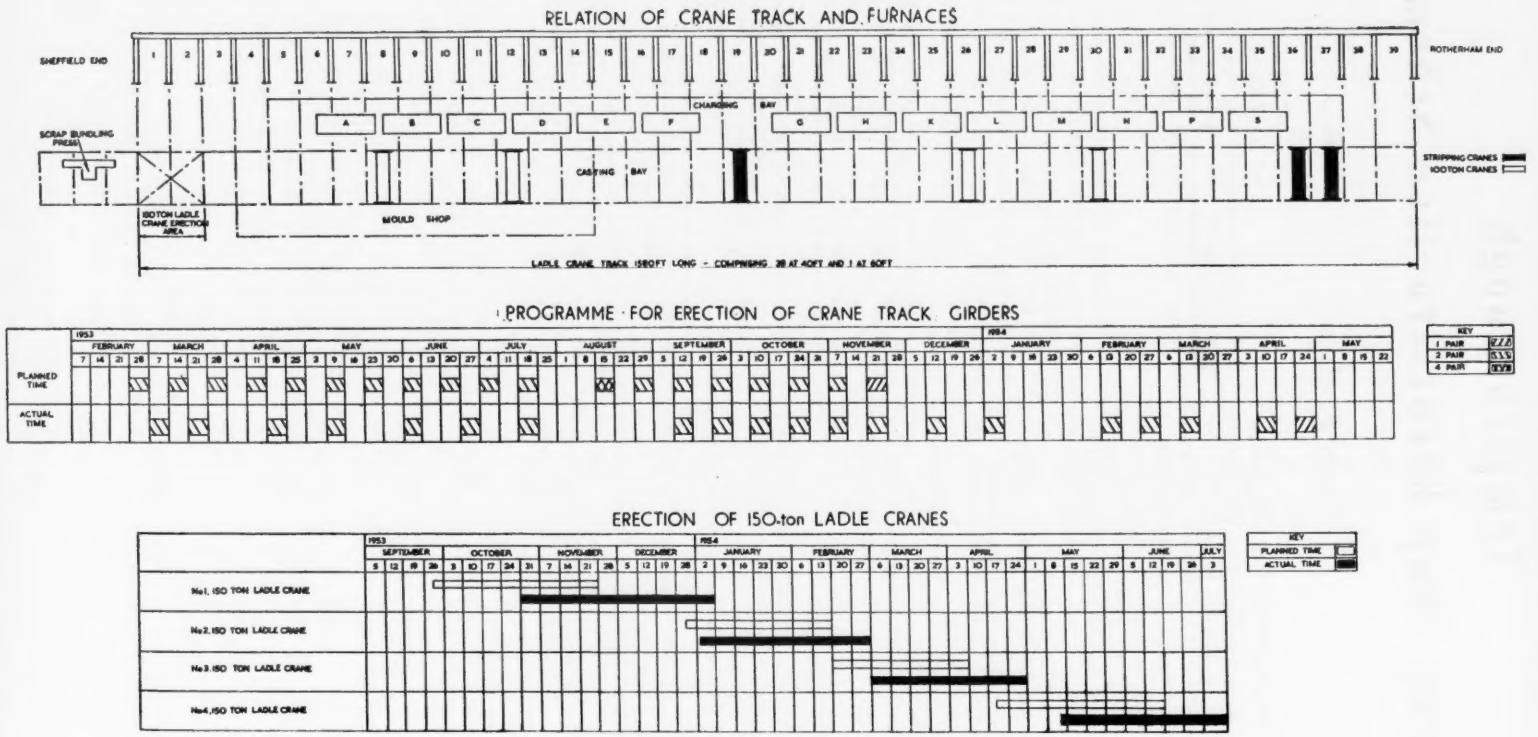


Fig. 1—Erection of crane track and 150-ton ladle cranes

in operation. This initial plan was in three stages.

1. The engineering department produced a plan for the erection of the crane track girders which was discussed in joint consultation with the production management.

2. Deliveries of the crane track girders and the ladle cranes from the suppliers had to be co-ordinated with the rest of the programme.

The need for timing the exact delivery date of the girders was important because the existing crane rail had still to be used; co-ordination between the dismantling of the old girders and delivery of the new was necessary to maintain the erection sequence.

The critical period with the ladle cranes was the delivery and erection of the third and fourth cranes. These had to be ready for work immediately before the yearly 'shut-down' to enable Nos. 1 and 2 cranes to be transferred to the opposite end of the shop.

Suppliers both of the track girders and ladle cranes fulfilled all delivery requirements at the right times.

3. Planning of all preparatory work was necessary before any erection could commence. Here the various maintenance sections made valuable contributions.

All the planning made it possible to prepare a complete programme and Fig. 1 shows how performance compared with the plan.

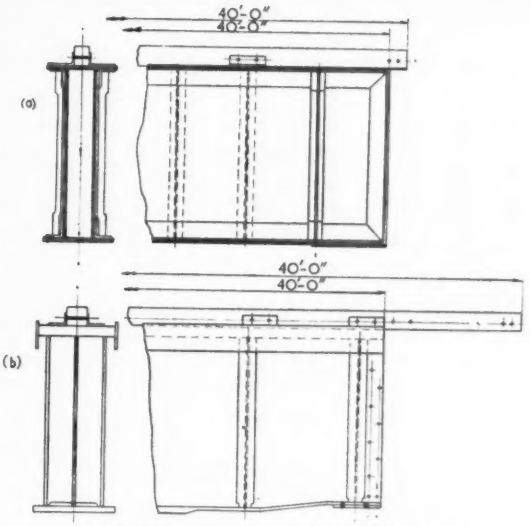
Maintaining Production

The project involved the renewal of the complete ladle crane track in a melting shop more than $\frac{1}{4}$ mile long.

Seventy-six girders, each 40 ft long and weighing $12\frac{1}{2}$ tons, were to be replaced by similar number of 16-ton girders, while two 60-ft girders each weighing 22 tons were to be replaced by two of 29 tons.

Four 150 tons' capacity ladle cranes, each weighing 250 tons were to be erected, while the four existing 100 tons' capacity cranes, each weighing 200 tons, were to be dismantled.

The actual erection time for all the track girders was 60 weeks, and 36 weeks for the ladle cranes.



(*a*) Old 100-ton crane girder, weight about $12\frac{1}{2}$ tons
(*b*) New 150-ton crane girder, weight about 16 tons

Fig. 2—End connection for old and new crane girders

In the pit of a melting shop working 20 shifts a week this would have been a big undertaking. It had to be carried out in a shop where 11 of the furnaces are always in use, where 21 shifts are worked 50 weeks in the year, where most of the casts are poured uphill, and where all stripping is done.

It was inevitable that some interruption of steel-making operations would ensue, and that there would be less flexibility of crane movement during each phase of the renewal. Some production losses were inescapable.

Co-operation between maintenance and production personnel ensured a minimum loss of production. An estimate of total production losses during the change-over showed that it was about 0·25%.

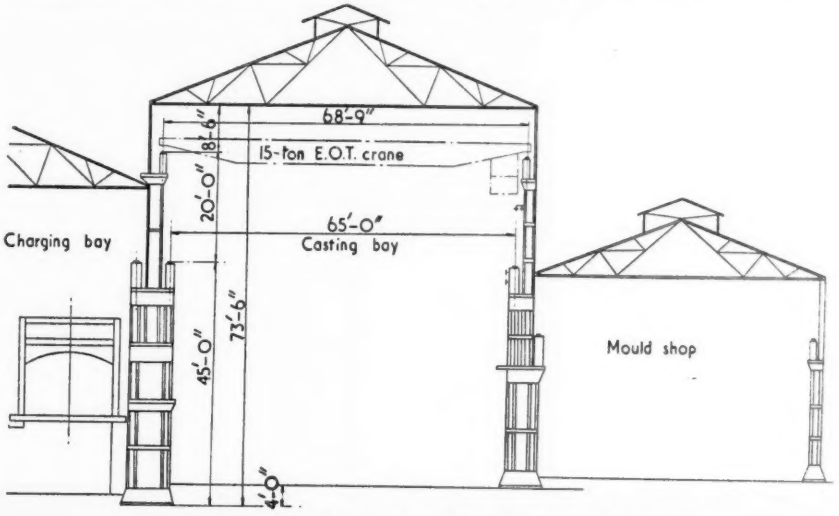


Fig. 3—Cross-section of Templeborough melting shops

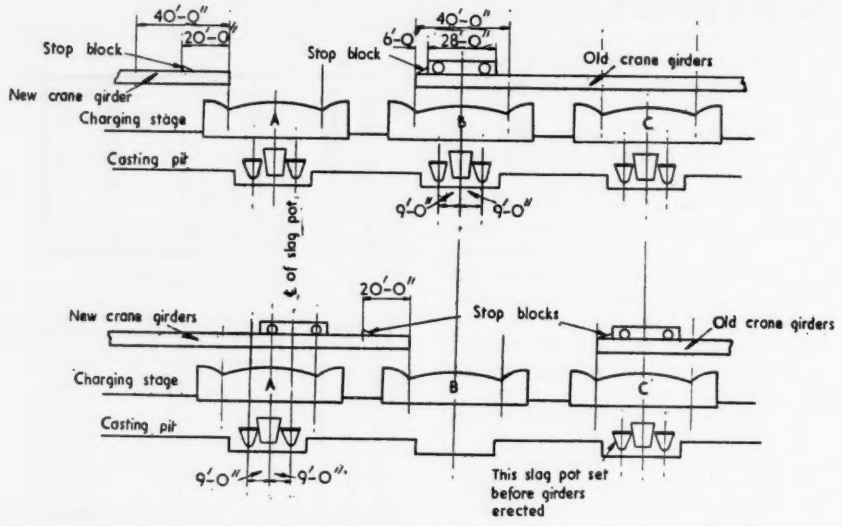


Fig. 4—Procedure for erection of new crane girders, showing positioning of safety stop blocks

During the period under review total production was considerably in excess of 500,000 tons.

PART I. RENEWAL OF THE LADLE CRANE GANTRY

Site Survey

In the 35 years of their existence some settlement of building column bases had taken place, causing the crane tracks to deviate from the original line and level. Hence the installation of new tracks provided an opportunity to rectify this condition as far as the structure of the building would allow. To determine what could be done, a survey of the tracks was made whilst the shop was working.

The girders were measured for length and checked against the centres of the shop columns; neither the girder lengths nor the pitch of the shop columns were found to agree with the nominal dimensions. This led to the first problem, since it was intended to install the new girders one by one, beginning at one end of the shop. It was necessary for the new girders to be made accurately to a standard length, except for certain locations determined by the survey, where longer girders were necessary because of discrepancies in the lengths of the existing girders and the centres of the building columns.

The gantry was next checked for line and level. Alignment was checked by the use of a theodolite mounted on a special stand set up on the walking platform attached to the crane-track girders. The levelling was done by measuring with a tape from an established datum near the column base to the column cap. The span of the gantry was measured directly with the tape.

The lining and levelling was completed in three weeks, and showed that considerable settlement had taken place. The results of this survey are given in Table I.

Design of Girders

The main problem, as already described, was that of getting the exact length. Since the limits to

Table I
SURVEY OF TRACK

Column No.	Level below datum, in.		Span (nominal 65 ft), in.	Cumulative error of column centres along shop, in.
1	0	0	±0	+3/8
2	0	0	−1/2	+3/8
3	0	0	+1/8	+3/16
4	0	0	+1/8	+1/16
5	7/16	0	−1/8	+1/16
6	2 1/4	1/16	−1/4	+1/16
7	1 7/8	3/16	+1/8	+1/8
8	1 7/8	9/16	+5/8	+1/8
9	1 3/8	9/16	+3/8	+1/4
10	1 1/4	1 1/16	+1/8	+3/8
11	1 1/4	2 5/16	+1/2	+1/2
12	1 3/4	3/4	+1 3/8	+5/8
13	1 1/2	5/16	+1 5/8	+11/16
14	2 1/8	13/16	+1 1/4	+11/16
15	3 9/16	1 7/16	+3/4	+11/16
16	4 1/16	11/16	+1 3/8	+3/4
17	5 3/16	15/16	−1 5/8	+5/8
18	4 9/16	1 1/4	−1 1/2	+5/8
19	4 11/16	1 13/16	−1/2	+11/16
20	4 1/4	1 7/16	−7/8	+3/16
21	5 7/16	1 5/16	−1 1/8	+7/8
22	4 11/16	1 1/16	−7/8	+7/8
23	4 5/16	1 9/16	−5/8	+1 1/16
24	4 11/16	1 5/16	−1 1/2	+1 3/16
25	3 3/4	1 5/16	−7/8	+1 5/16
26	5 5/16	1 5/16	+1/8	+1 1/16
27	3 9/16	1 5/16	−1 3/8	+1 1/2
28	3 15/16	1 10/16	−1 1/2	+1 1/2
29	3 9/16	2 3/8	±0	+1 1/2
30	4 11/16	3 1/8	−3/4	+1 1/2
31	4 13/16	3 1/8	−2 1/4	+1 1/2
32	3 13/16	1 7/8	−1 3/4	+1 1/2
33	4 5/16	1 11/16	−2	+1 3/4
34	3 1/2	2 1/4	−2	+1 3/4
35	3	2 1/16	−1	+1 3/4
36	2 1/4	1 15/16	−1	+1 7/8
37	1 11/16	1 13/16	+1/8	+1 5/8
38	2 7/16	1 15/16	−1 1/2	+1 3/4
39	1 3/4	1 11/16	−3/4	+1 3/4
40	3 3/4	1 15/16	−3/8	

which the girders were manufactured were $\pm\frac{1}{4}$ in., end-milling was needed to ensure dead length.

Facilities were not available for the machining process and the original design was abandoned in favour of a fish-plate type of connection.

The girders were of all-welded, fabricated construction and Fig. 2 shows the end connections of the old and new-type girders together with the relative weights of the girders.

Survey of the track showed that the existing rail billets were in good condition. Accordingly they were used again in the same relative positions in which they had previously been fixed.

Planning of Erection

If the renewal of the girders were to proceed without impeding production, full co-operation of all concerned was essential. Considerable time was spent on this phase of the project, for while the girders were changed, sections of the track would be closed to the cranes, and therefore no tapping of furnaces could take place in these locations. At this stage it was assumed that dismantling of the old girders would commence after a furnace had been tapped, and that with a slow charge 12 h would elapse before the crane was required again.

Erection of the girders would be carried out with the high-track cranes (Fig. 3). This meant an almost direct lift on the furnace side, but on the other side the girders would have to be pulled into the column caps. Care would have to be taken with the live trolley wires which would be insulated with split rubber tube for the section being dealt with.

To avoid trouble in the actual operation and as a precautionary measure, all the column cap bolts and bolts connecting girder to girder were changed.

It became clear that the erection of new girders should be carried out in fours or eights, and never in twos or sixes. By doing this the job was phased so that on each occasion the same conditions existed around the furnaces.

During the planning of the job, safety factors were given special attention. For instance, the procedure of fixing stop blocks set out in Fig. 4 was adopted, together with the use of flag- and whistlemen, while the stop blocks themselves were of a spring-loaded buffer type.

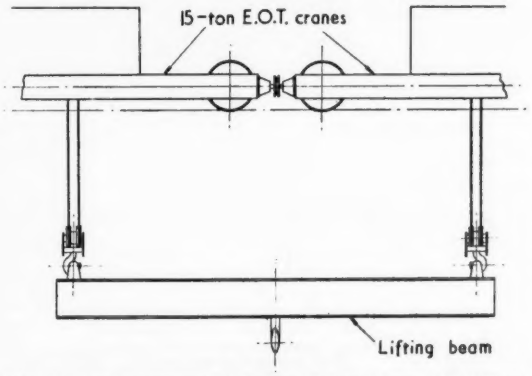


Fig. 5—Arrangement of 40-ton lifting beam for lifting No. 3 ingot stripping crane, and for erection of 150-ton ladle-crane girders

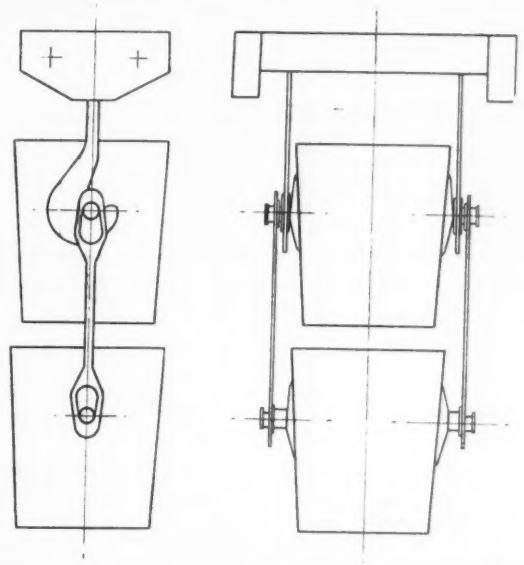


Fig. 6—Arrangement of ladles for test on 150-ton ladle cranes

At this stage, planning was also concerned with the erection of the cranes, but detailed plans were made nearer the time of erection, and will be described later. However, a block plan was prepared, based on delivery promises for the new girders and the cranes. This is referred to in Fig. 1.

Preparatory Work

To reduce the total erection time of the new girders to the bare minimum, certain preparatory work was undertaken:

(i) The suppliers of the girders fitted them together in threes to obtain good butt joints in the track rail and to make certain that the fishplates fitted correctly. After checking the lengths, the first two girders were despatched, while the third one was retained to mate with the next pair

(ii) Platforms supporting the furnace-door lifting gear which were fastened to the existing girders were detached and supported independently

(iii) The walking platform between the pit and stage girders was cantilevered from the stage side girder only

(iv) All necessary bolts were changed

(v) The accumulated dirt was swept off the crane tracks.

Site Work on Girders

A site at one end of the pit (the Sheffield end) was allocated to the engineers where the girders were to be received and checked.

The **T**-bar brackets and the **T**-bars were to be fitted as well as the packs needed to ensure that the new girders were level when placed on the column caps.

Erection

It was found that eight girders could be erected without interfering with steelmaking operations. That number was prepared and erected, erection time was checked, and working arrangements were examined. All were found to be satisfactory.

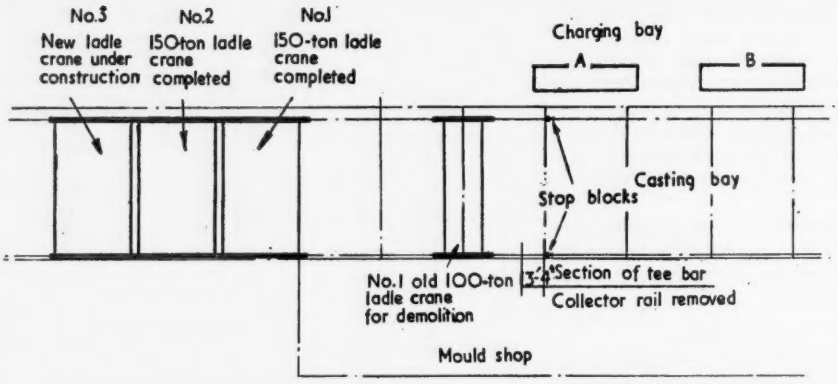


Fig. 7—Demolition of No. 1 ladle crane

Beyond this point erection took place over the furnaces. The routine was as follows:

(i) Girders were placed on site and the T-bars fitted. Packing pieces to bring the crane track back to level were fixed to girders, and final detachment of walking platform from old girders was made.

(ii) The melting-shop management was informed that the job was ready to begin. They in turn told the site engineers when the furnace involved would be tapped and when work could begin. They also informed the crane drivers of the safety precautions and instructed the flagmen.

(iii) Stop blocks were fitted and the girders were released to be ready for lowering

(iv) The old girders were lifted down

(v) New girders were lifted and temporarily fixed on the furnace side. These were then lined up in their correct positions and the fitting of diaphragms and fish-plates began, with the aid of pneumatic nut runners.

(vi) Walking and motor platforms were re-fixed and the melting-shop management informed so that full flame could be used in the furnace

(vii) The last two girders were lifted up and fixed

(viii) Stop blocks were taken down and melting-shop management was informed of the completion of job.

At the beginning of the job two 12-h shifts were employed. Later only one shift was necessary.

Table II shows typical times for the erection of four girders, one set of times being for the beginning of the operation, and one set of times for the end.

PART II. ERECTION OF 150-TON LADLE CRANES

Choice of Site

A survey of the shop showed that the Sheffield end was the best position to erect all four new cranes. The reasons influencing this decision were:

(i) Site was clear of furnaces and pit, and erection operations would not affect production of the shop

(ii) The transport of ingots to the soaking pits is via the Rotherham end of the shop. As the greater proportion of ingots is stripped at that end, considerable interference to production would have occurred if any erection had been done in that area

(iii) It was clear that No. 3 stripping crane would have to be removed from the track to pass two of the new ladle cranes to the Rotherham half of the shop.

The proposed site was agreed upon and cleared; the area is indicated in Fig. 1.

Planning

In planning any lifting operation the first question is, with what is the lifting to be done? In this case four 15-ton overhead cranes were working on a track immediately above the ladle-crane track; their normal duties were to serve the scrap bundling press and the pit. By arrangement, these cranes were loaned at suitable intervals to do erection work.

Analysis of the detail drawings of the new ladle cranes together with the crane power available showed that the best method of erecting the main units of the new cranes was by using a lifting beam suspended from the hooks of two of the 15-ton cranes.

The centres of the shackles on the lifting beam for attaching it to the hooks on the 15-ton cranes were made identical with the centres of these hooks when the cranes were buffer to buffer. This was

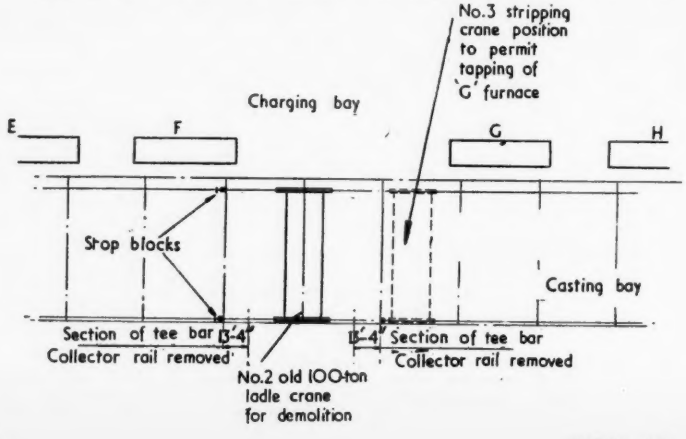


Fig. 8—Demolition of No. 2 ladle crane

necessary because when the main girders of the new cranes were being placed on the track, the hoist blocks of the 15-ton cranes would be near the top position, and undue angularity of the hoisting ropes might cause them to ride over the sheaves leading to subsequent damage or failure of the ropes. Figure 5 shows the arrangement of the lifting beam.

To ensure that in long travel operations the two cranes worked in unison, suitable brackets were made and fixed to join firmly together the adjacent end carriages of the two cranes.

The lifting beam, ropes, and tackle were manufactured to a programme to suit the delivery of the cranes. Each crane was despatched from the maker's works as nine main components: two main and two auxiliary girders, end carriages, main trolley frame, complete auxiliary trolley, and cab.

Erection

The sequence of erection was as follows. Two end carriages were placed on the track and suitably chocked and secured, followed by one main girder, two auxiliary girders, auxiliary trolley, one main girder, main trolley and, finally, the cab. These components were provisionally secured by black bolts, and when the erection of these major items was completed the fitted bolt connections were made.

All the electrical wiring, motors, controllers, contactors, lubrication and air conditioning system, long travel shafts, and drive were fitted on the site, as were the main hoist drums and all mechanical and electrical gear. The auxiliary trolley was delivered completely fitted with electrical, mechanical and lubricating equipment and was erected as a unit.

Work began on the erection of:

(i) No. 1 crane on October 24th, 1953, when 44 track girders were erected. Crane erection time was ten weeks.

(ii) No. 2 crane on December 30th, 1953, when 56 track girders were erected. Crane erection time was nine weeks.

(iii) No. 3 crane on February 27th, 1954, when 68 track girders were erected. Crane erection time was eight weeks.

(iv) No. 4 crane on May 7th, 1954, when 78 track girders were erected. Crane erection time was eight weeks and one day.

Testing of Cranes

The weight of an 80-ton ladle when filled with pig iron was not sufficient to provide a test load for the main hoist; the required load was obtained by slinging two ladles as shown in Fig. 6, the total weight of ladles, lifting straps, and pig iron being 187½ tons. The auxiliary hoist was also tested and the usual deflection tests were carried out on the main and auxiliary girders.

The electrical equipment was thoroughly tested and, some months later, the power consumption of all the motors was checked in collaboration with the makers, under operating conditions. The tests showed that the cranes met the specification required.

Table II
TYPICAL ERECTION TIME FOR 4 GIRDERS

Phase	Beginning of operation, h	End of operation, h
i	...	...
ii	...	...
iii	3	2
iv	1	1
v	4–5	3½
vi	3	2
vii	4–5	3½
viii	...	...

Note: Phases (iv) and (vi) overlapped to a certain degree.

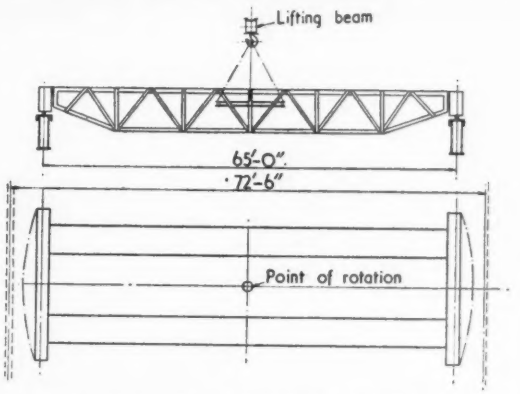


Fig. 9—Arrangement for lifting No. 3 ingot stripping crane

PART III. DEMOLITION OF THE OLD 100-TON LADLE CRANES

Planning

The many factors involved in this apparently simple phase of the scheme were discussed in the preliminary investigations. The main points to be considered were:

(i) Position of the cranes for demolition
(ii) Timing of demolition to suit the new crane erection programme, and the crane girders erection programme
(iii) Minimum of interference with production.

It became clear that the crane track would be completed before all the new cranes were erected, but free track space, furnace and pit operations, and the difficulty of manning the old and new cranes indicated that the most convenient arrangement would be to put two of the new cranes into operation and remove two old ones.

The erection of the track girders would be sufficiently advanced to permit demolition of the first two cranes in any part of the shop except the extreme Rotherham end. Various schemes were considered and eventually it was agreed to dismantle the old No. 1 crane at a position on the Sheffield side of 'A' furnace, shown in Fig. 7. This would make the two newly proved ladle cranes inoperative, but leave the remaining three old cranes to cover the production requirements of the pit during the demolition period; there would be no interference with the operations of No. 3 stripping crane in the centre of the shop.

As the site was agreed, the method of dismantling was considered. The crane was to be scrapped so that, where convenient, oxy-acetylene torches could

be used to cut away sections, and this required adequate precautions against fire. It was desirable to remove the crane in as few pieces as possible, the limiting factor being the lifting capacity of the overhead cranes.

It was now possible to prepare a detailed plan for the demolition of the ladle crane, incorporating the necessary labour, transport, and safety requirements. The estimated time for the job was 36 h.

No. 1. 100-ton Ladle Crane

The demolition of this crane was arranged to begin at 6 a.m. March 11th, 1954, but, because of the tapping of furnaces in the area, a start was not made until 8.15 a.m. The sequence of demolition was the main hoist drums, main trolley gears and pedestals, main trolley frame, auxiliary trolley complete, auxiliary girders, driver's cab, main girders, and end carriages. The last piece was lowered to the ground at 8 a.m. on March 12th, 1954, giving a total time of just under 24 h.

No. 2. 100-ton Ladle Crane

The site chosen for the demolition of this crane was the centre of the shop as shown in Fig. 8, with Nos. 1 and 2 new ladle cranes servicing furnaces

E. No. or S.E. No. | Date: 3.3.54 | S. P. & T. SHEET 1 of 1 | Form P.M. 10A

OPERATION LAYOUT
(RECORDS OFFICE COPY/COST OFFICE COPY)

Checked | Approved | Typed: ML.

Accts. Ref. No. | No. in Sets | Description: DISMANTLE AND RE-ASSEMBLY OF NO. 3 STRIPPING CRANE. | Operation Layout No.: 257/71/209

Total No. Reqd.	Process No.	BIN No./DWG. No. Dept	Machine No. or Group	PART NAME or MATERIAL / PROCESS	TOTAL EST. LENGTH and/or WEIGHT / LABOUR Total Est. Hrs.	Grade	No	MATERIAL Rate	Unit	£ Value	LABOUR and ON COST Wage Rate	On Cost	£ Value
	1	751		Position crane over ingot moulds.	½ 4697 2 ½ 4723 2 ½						2.0p.m. Fri.16/7/54		2.15p.m. Fri.16/7
	2	751 761		Remove cotter from ram and proceed to hoist up the dog box	4 4697 2 4 4723 2 8 4840 4 2						2.15p.m. Fri.16/7		4.15p.m. Fri.16/7
	3	751 761		Move crane, position over the ingot moulds and prepare necessary packings, etc. for the removal of dog box.	6 4697 2 6 4723 2 12 4840 4 3						4.15p.m. Fri.16/7		7.15p.m. Fri.16/7
	4	759		Burn off the stop blocks at the bottom of the slides.	4 4825 2 4 4829 2 2						5.0p.m. Fri.16/7		7.0p.m. Fri.16/7
	5	751		Lower down dog box on to the ingot moulds.	2 4697 2 2 4723 2 1						7.15p.m. Fri.16/7		8.15p.m. Fri.16/7
	6	759		Burn off the dog box ropes.	2 4825 2 2 4829 2 1						8.15p.m. Fri.16/7		9.15p.m. Fri.16/7
	7	751 761		Remove dog box ropes.	2 4697 2 2 4723 2 4 4840 4 1						8.30p.m. Fri.16/7		9.30p.m. Fri.16/7
	8	751 761		Remove dog box.	4 4697 2 4 4723 2 8 4840 4 2						9.30p.m. Fri.16/7/54		11.30p.m. Fri.16/7
	9	751 761		Move crane and position over ingot moulds, prepare all necessary packs for removal of stripping crab.	8 4697 2 8 4723 2 16 4840 4 4						11.30p.m. Fri.16/7		3.30a.m. Sat.17/7
	10	751		Lower down stripping crab into the bottom of the hangar frame and proceed to sling.	2 4697 2 2 4723 2 4 4840 4 1						3.30a.m. Sat.17/7		4.30a.m. Sat.17/7
	11	759		Burn off the wire ropes on the stripping crab.	2 4825 2 2 4829 2 1						4.30a.m. Sat.17/7		5.30a.m. Sat.17/7
	12	751 761		Remove stripping crab ropes.	4 4697 2 4 4723 2 8 4840 4 2						5.0a.m. Sat.17/7		7.0a.m. Sat.17/7
	13	751 761		Remove stripping crab from the main assembly, lower down on to the packs.	6 4697 2 6 4723 2 12 4840 4 3						7.0a.m. Sat.17/7		10.0a.m. Sat.17/7

Fig. 10—Operation layout for dismantling and reassembly of No. 3 stripping crane

Item	*Detail of Work*
1	**Prepare remove dog box**
2	**Remove ropes**
3	**Remove dog box**
4	**Prepare remove stripping crab**
5	**Remove ropes**
6	**Remove stripping crab**
7	**Disconnect electrics**
8	**Sling hanger frames**
9	**Remove hanger bolts**
10	**Remove crab from booms**
11	**Remove hanger**
12	**Remove booms from track**
13	**Move 150-ton cranes down track**
14	**Replace booms on track**
15	**Sling hanger frame**
16	**Replace crab on booms**
17	**Couple-up electrics**
18	**Rebolt hanger frame**
19	**Replace stripping crab and ropes**
20	**Fit dog-box ropes**
21	**Fit stop-blocks to mast**
22	**Fit ram**
23	**Clear site**
24	**Riggers assisting all operations**

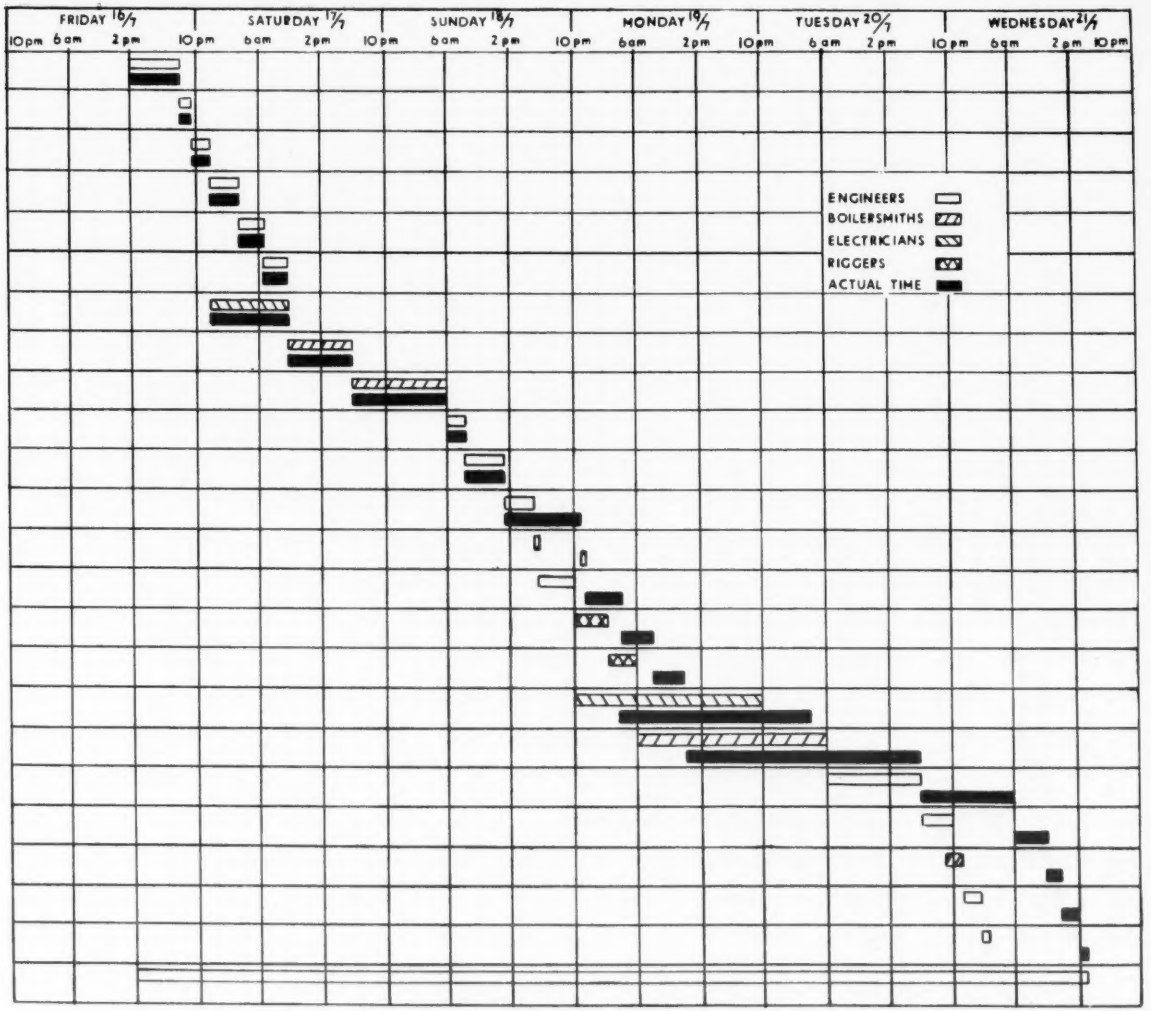


Fig. 11—Performance record of dismantling and reassembly of No. 3 stripping crane

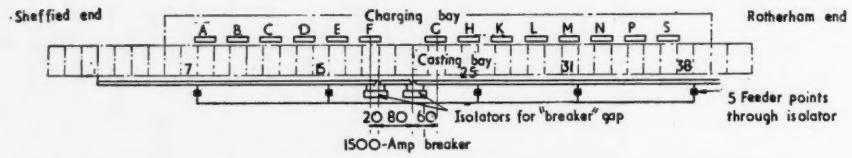


Fig. 12—Layout of electrical supply to 150-ton ladle crane track

'A' to 'F,' and Nos. 3 and 4 old ladle cranes servicing furnaces 'G' to 'S', the No. 3 stripping crane being inoperative during the demolition period. The same plan of demolition was adopted as for No. 1 crane, except that the main trolley was more thoroughly cleaned to permit quicker burning of the bolts securing the main trolley components. Work commenced on March 30th, 1954, and was completed in 18 h.

Nos. 3 and 4. 100-ton Ladle Cranes

Transfer of Nos. 1 and 2. 150-ton Ladle Cranes.

The demolition of these cranes could be done only at the Rotherham end of the shop, where most of the stripping takes place, and through which all slag and ingot traffic passes on its way to the slag bank and the soaking pits.

Furthermore, to enable the shop to work, the old cranes had to be replaced immediately with new ones. This required the removal from the crane track of the No. 3 stripping crane and its replacement when the ladle cranes had passed through, and the mid-summer stop period was the only suitable time to do this work.

The provision of a lifting frame (Fig. 9) attached to the bridge girders of the stripping crane enabled the structure to be lowered as a unit when the trolley and mast were removed, thereby effecting a useful reduction in the time of the operation.

Figure 10 is an example of the detail planning, and Fig. 11 shows how the performance compared with the plan.

PART IV. ELECTRICAL

Power Supply

Electric power is supplied to the 100-ton ladle cranes through a pair of copper trolley wires supported on insulated bolts and ears from angle brackets attached to the building stanchions. The wires are fixed at a height above the crane track of 11 ft 0 in. They run the length of the track and are fed at three points.

The supply to the new cranes was to be by a **T**-bar system fitted to the new track girders. The new distribution scheme is shown on Fig. 12, where it will be seen that power is supplied through isolating switches to five feeder points. The system was installed in conjunction with the track girder erection programme. Two additional isolators were fitted near the centre of the shop to enable one half of the track to be isolated for maintenance purposes.

Change-over from Old to New Power Supply

It was clear that when the main hoist of the 150-ton crane was placed in the normal teeming position, it would foul the trolley wires, and they would have to be removed to enable the new cranes to be put to work. The change-over plan was arranged:

(i) To convert Nos. 1 and 2 old ladle cranes and No. 3 stripping crane to **T**-bar collectors
(ii) To dismantle the trolley wires from the Sheffield end of the shop to 'H' furnace.

The dismantling of these trolley wires took place as soon as the new track girders were erected to 'M' furnace. This enabled Nos. 1 and 2 new ladle cranes to service furnaces 'A' to 'F' while the Nos. 1 and 2 old ladle cranes were able to service furnaces 'A' to 'H,' although their main duty was with furnaces 'G' and 'H.'

When No. 1 150-ton ladle crane was tapping 'F' furnaces, Nos. 1 and 2 old cranes on the Rotherham side of it would interfere with the operations of the stripping crane, and cause considerable interruption to pit operations. This condition was bound to obtain during the proving period of the new cranes, and until the old cranes could be removed from the track. The proving time for the cranes was set at 14 days.

As the erection of the girders took place beyond 'M' furnace, No. 3 old ladle crane was converted to **T**-bar collectors, but still retained the trolley wire collector gear. This was done to enable the trolley wires between furnaces 'H' and 'M' to be dismantled. During this period, therefore, No. 3 crane serviced furnaces 'G,' 'H,' 'K,' and 'L,' leaving furnaces 'M,' 'N,' 'P,' and 'S' to the No. 4 crane. In the case of a breakdown on No. 4 crane, No. 3 crane could be changed to trolley wire collectors in a few minutes, while a breakdown to No. 3 crane could be taken care of by No. 1 150-ton ladle crane.

When the track was completely erected, the No. 4 crane and the two stripping cranes at the Rotherham end of the shop were converted to **T**-bar collectors, and the remaining trolley wires dismantled.

Acknowledgments

The author wishes to thank the directors of Steel, Peech and Tozer for permission to publish the paper, as well as the Chief Engineer and members of his staff for their help in its preparation.

The B.I.S.R.A. Suction Pyrometer for Open-hearth Furnace Uptakes

By R. Barber, D. Meachen, and W. Bateman

SYNOPSIS

A suction pyrometer, with its shield system inside the water cooled probe, is shown to give reasonable accuracy and a much improved life in the temperature range 1000–1400° C. The paper indicates how the accuracy and life were determined, and gives recommendations and practical hints for the use of the instrument in determining the temperatures of preheated air, particularly in open-hearth furnaces uptakes. 1383

Introduction

SUCTION PYROMETERS have proved to be most useful instruments for the measurement of gas temperatures. Various designs of suction pyrometers have been made and used, but they were not ideally suited to the exacting conditions of service and accuracy required for the open-hearth furnace.

Halliday[1] and Cashmore[2] have described pyrometers using mullite or alumina shields and found a useful life for the pyrometer in an open-hearth furnace uptake of 6 h; however, both authors found difficulties due to spalling of the shield. The application of the instrument to open-hearth furnace work has largely been sponsored by the Steelmaking Instruments Sub-Committee of the British Iron and Steel Research Association. A robust instrument of known accuracy was needed which was easy to use and maintain and able to last, under open-hearth conditions, for at least a complete heat without attention. This paper describes the pyrometer that has been evolved and gives a guide to prospective users to enable them to get the maximum benefit from such an instrument.

When a thermocouple or other device is used to measure gas temperature, its reading will lie between the gas temperature and the temperature of its surroundings. To measure the gas temperature, convective heat transfer from the gas must be increased and the heat transfer from the surroundings by radiation must be reduced. In a suction pyrometer the couple is surrounded by a series of shields and the gas is aspirated at a high velocity past the thermocouple shields. Land and Barber[3] have shown how the accuracy of the pyrometer varies with the number of radiation shields. At low temperatures the effect of radiation is generally small, but when either the gas or the surrounding temperature is above 400° C, some means of drawing the gas past the couple to increase the convective heat transfer and a simple shield system to reduce radiation are needed. At higher temperatures, a more complex shield is needed.

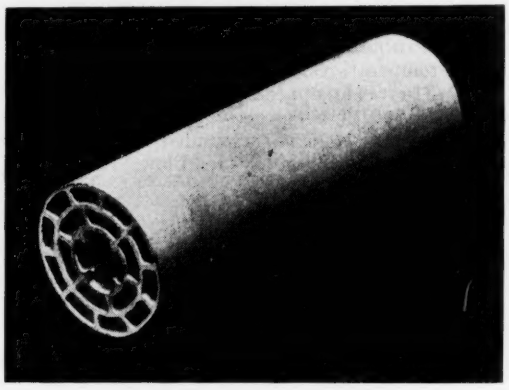


Fig. 1—Sillimanite shield

THE B.I.S.R.A. INTERNAL-SHIELD SYSTEM FOR OPEN-HEARTH FURNACES

The corrosive attack of the waste gas on the shield of a conventional suction pyrometer led to the idea of withdrawing the assembly inside the water-cooled probe. A water-cooled probe is necessary on any pyrometer sampling such hot gases and this idea introduced no extra complication.

This practice brings a number of important advantages. The shield is not exposed to attack by the gas when it is not in use for temperature measurement, and while in use its temperature is never greater than the air temperature. Precautions against spalling are not necessary as the shield is held together by its holder and the water-cooled probe. Finally, because the thermocouple system is surrounded by the sensibly constant temperature of the water-cooled probe, the accuracy at any gas temperature is independent of the temperature of the uptake walls.

An extruded refractory shield system (Fig. 1) was designed for use inside the water-cooled probe[4] which had been designed for the conventional external system. The shield system is made of sillimanite

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Mr. Barber is with Land Pyrometers Ltd., and Mr. Meachen and Mr. Bateman are with the Association's Steelmaking Division.

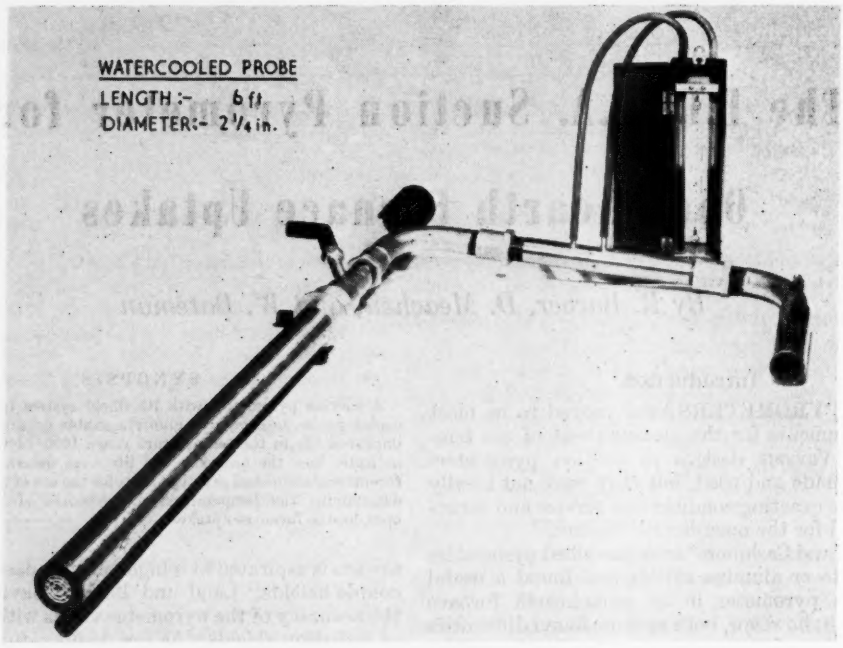

Fig. 2—Suction pyrometer with Venturi and ejector. The refractory shield can be seen inside the water-cooled probe

and comprises three concentric tubes with ribs between the tubes. Experiment and calculation show that the accuracy of this arrangement is at least as good as, and more reliable than, the conventional type using a similar shield. The complete assembly, shown in Fig. 2, is now accepted practice for work in the temperature range 1000–1400° C (B.I.S.R.A. British Prov. Pat. No. 21124, held by Land Pyrometers Ltd.). The following sections describe the use of this instrument on open-hearth furnaces.

DETERMINATION OF ACCURACY

One of the chief handicaps to the more rapid development of suction pyrometry has been the lack of a suitable standard of gas temperature. Consequently, accuracy has in the main had to be assessed by indirect methods, and these methods have required thorough experimental verification. Land and Barber showed that the accuracy of a pyrometer could be estimated by plotting the temperature reading at various gas velocities. Earlier work had led to the development of a multi-shielded system made in metal which could be used up to about 1100° C and which was sufficiently accurate in the region of 1000° C to enable it to be used as a comparison standard. Finally, an instrument was made at B.I.S.R.A. in which the measuring element was a bare rare-metal thermocouple. A second couple was embedded in the inner refractory shield, and this consequently gave a measure of the temperature of the effective surroundings of the bare couple. The difference between these two couples under operating conditions at about 1100–1200° C was only 10° C. This indicated that the control couple was unlikely to be in error by more than 1° or 2° C. Hence this instrument could be used as a second comparison standard for short periods at higher temperatures than the metal shield. As the bare couple contaminated after several hours, this pyrometer is not suitable for routine use.

The internal-shield instrument was checked against the two standards: firstly, in a power station in the range 900–1000° C, and secondly, in an open-hearth uptake against the bare pyrometer. Its performance was also checked by noting the shape of the temperature/velocity curve. Reassuring agreement was obtained between these methods, and the accuracy of the working pyrometer can be accepted as proved.

The accuracy of a suction pyrometer depends on the velocity at which the gas is aspirated through the shields. A hot-gas velocity of 500 ft/s is about the optimum value. Table I gives the mass flow of gas required to obtain this velocity in the shield system at various temperatures.

Table II gives an approximate guide to the error to be expected with a correctly operating pyrometer. As the shield system is surrounded by water-cooled metal, the couple will always read low.

Table I

MASS FLOW OF GAS REQUIRED FOR 500 ft/s HOT-GAS VELOCITY

Temperature, °C	Mass Flow, lb/h
1000	150
1200	130
1400	115

It is desirable to check the accuracy of the pyrometer in use. The standards used to establish the accuracy are too elaborate for routine use. A convenient method uses the property that at high velocities (above about 100 ft/s) the error of the pyrometer is approximately inversely proportional to the gas velocity. Consequently, the change in reading observed when the operating-gas velocity is halved is equal to the initial error of the pyrometer. When the pyrometer is operating efficiently this change is often less than normal fluctuations. If it is not sufficient to say that "the error is less than the scatter," then a value can be obtained by reducing the gas velocity to a quarter of its working value, which gives a change in readings of three times the original error. Figure 3 shows schematically the record of a preheated-air half-cycle in an uptake in which the velocity has been dropped to half and then returned to full flow during the recording.

It has been found that the pyrometer takes about 2 min to reach equilibrium after a step change in temperature or gas velocity. This time delay should be borne in mind when the initial part of the curve is being analysed.

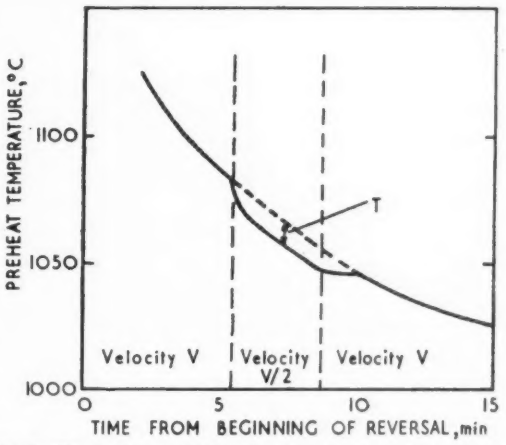

Fig. 3—Typical record of preheat temperature as velocity is halved during a reversal. The temperature difference *T* is equal to the error of the pyrometer at velocity *V* ft/s

THE USEFUL LIFE OF THE SHIELD SYSTEM

The useful life of a shield may be defined as the length of time for which it can be relied on to give accurate readings without attention. The 'death' of most shield systems is the eventual fall in accuracy due to attack by dust in the gas and the blocking of openings. The conditions vary widely, even between furnaces on the same stage. It is impossible to generalize on the life to be expected, but it is possible to indicate some of the factors that affect it.

The most marked reduction in life is due to sucking in any of the waste gas, and this must be avoided. The pyrometer must be switched off before the waste gas enters the uptake and not switched on again until the next reversal.

The refractory shield is completely protected from attack by waste gases by the water cooling, and so when no suction is applied there is no attack.

Experience has shown that the life can be doubled by delaying the start of the suction until 10 s after the air reversal. An even greater increase may be possible if the delay is increased, and further work is needed to determine the optimum delay time.

A second factor that can affect the life is the positioning of the probe in the uptake. The pyrometer should point slightly downstream to the waste gas. The momentum of the slag particles then takes them past the end of the probe and they do not accumulate on the shield. It is desirable to place the probe through the pitside wall of the uptake at a point nearer the chill wall than the end wall where it avoids the majority of the coarser material carried over during the waste-gas cycle. It should not be placed too close to the wall or it may give incorrect readings due to pockets of recirculating air, or infiltration through the uptake wall. Quite often an improvement can be obtained by properly engineering the installation. The provision of a convenient arrangement of the piping for water and air and a correctly made entrance to the uptake is far better than just knocking out a brick and taking the piping to some inconvenient point whose only virtue is that it already exists. With these facilities less time is required to remove the probe and more time is available for the replacement of shields and other maintenance. This results in a more reliable instrument.

The pyrometer has been found to give good accuracy until some of the openings in the shield are completely blocked. This raises the problem of how to detect the failure of the shield while the pyrometer is operating in the uptake. The most probable causes of incorrect readings are a reduction in compressed-air pressure (temporary or permanent) and the blocking of the shield: both result in a reduction in gas flow. Cashmore[2] has suggested the measurement of both volume and suction. These are not the only variables available, and where the pyrometer is left unattended it may be an advantage to choose a measurement which is easily recorded on the same multipoint instrument as the preheat temperature. A variety of measurements will indicate whether the flow has changed. To isolate the cause two readings are necessary (e.g. (2) and (4) in the following list):

(1) Gas flow
(2) Exit gas temperature
(3) Exit gas pressure (suction)
(4) Compressed air pressure.

For routine use the exit gas temperature has the

Table II

APPROXIMATE ERROR OF SUCTION PYROMETER INTERNAL SHIELD AT VARIOUS HOT-GAS VELOCITIES

Temperature, °C	Velocity, ft/s			
	200	300	400	500
1000	— 20	— 13	— 10	— 8
1200	— 50	— 33	— 25	— 20
1400	— 120	— 80	— 60	— 50

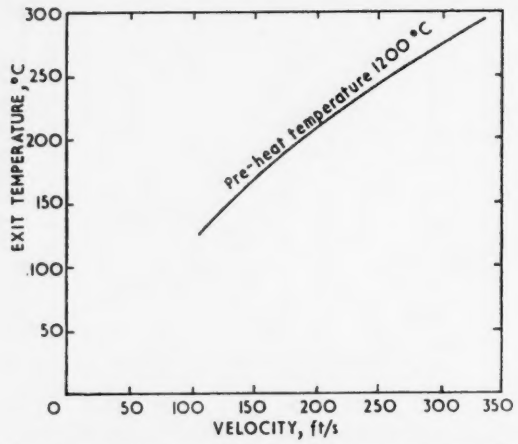

Fig. 4—Variation of exit gas temperature with velocity of gas through the refractory shield. Exit gas temperature of gases leaving the pyrometer

advantage that a base-metal couple can be recorded on the instrument that is being used to record the gas temperature. A serious fault in the performance is then visible at a glance. Figure 4 shows the correlation between gas flow and exit gas temperature for one pyrometer. The relationship will vary with the length and probably with the age of the probe, but the reading should provide a useful guide. A fall in exit gas temperature indicates a fall in gas flow.

During a works' trial on an oil-fired fixed 200-ton furnace on hot-metal practice, a life of three days in the furnace uptake was obtained. Comparable lives have been found for similar practice with oil plus coke-oven gas and tar plus coke-oven gas firing.

During these tests the suction pyrometer was automatically switched on 10 s after the furnace air reversal. The life may be improved when a longer delay is incorporated in the switching mechanism.

OPERATING HINTS

Water Cooling

The water pressure available determines the maximum distance which the pyrometer may be inserted into the furnace uptake. Sufficient water should be passed to prevent ' bumping ' due to the formation of steam, and the exit temperature should not exceed 70° C. ' Bumping ' can occur at exit temperatures below 70° C when, owing to low rates of flow, there is less mixing of the water within the pyrometer.

Tests have been carried out in a furnace uptake to measure the temperature rise on a 6-ft long pyrometer with various depths of immersion. Table III gives a guide to the pressure required and the quantity of water used.

In practice the water pressure to the pyrometer should be increased so that no ' bumping ' can be felt under the hottest conditions, i.e. during the refining period.

Before inserting the pyrometer, care must be taken always to see that it is filled completely with water leaving no air pockets.

Position

A good position for the pyrometer in an uptake is described on p. 345. The pyrometer is protected from most of the heavier dust and slag particles carried by the waste gases from the furnace, which are thrown towards the end wall. The pyrometer has been left in this position for two days with no suction applied and no material collected on the shields.

Suction

The most convenient method of obtaining the necessary flow is by means of compressed air or a steam ejector. The model used in the trial is shown in Fig. 2. With this model, approximately 100 lb/h of compressed air was used at a pressure of 20 lb/in². For the initial work it is desirable to meter the gases and consequently to control the gas velocity. A Venturi and manometer (Fig. 2) were used in the trials. For continuous use this is probably not the most convenient method. If the pyrometer is to be left unattended for any length of time it is desirable to have some indication that the pyrometer has functioned properly. The use of a base-metal thermocouple in the exit gases, as described in the previous section, is suitable for this purpose.

DESCRIPTION OF EQUIPMENT

Suction Pyrometer

The suction pyrometer* (Fig. 2) is designed so that the refractory shield or thermocouple sheath can be replaced without removing the thermocouple from the water-cooled probe. This means that a damaged shield may be replaced in a few minutes. The only hot part of the equipment which must be handled is the refractory shield with its holder which may be removed by using tools.

A Venturi is included between the pyrometer and the ejector to measure the flow of gases through it. This Venturi may be omitted during routine preheat measurements and the ejector coupled to the pyrometer directly. The probe has been designed to eliminate sharp bends and restrictions for the gas flow.

Automatic Cut-off Valve

In use in an open-hearth uptake the pyrometer is exposed to two different conditions. During the air cycle preheated air at 1000–1300° C is drawn into the pyrometer, and so long as no dust is present the refractory can last for a long time. However, when the furnace reverses, the pyrometer is surrounded

* Land Pyrometers Ltd.

Table III

INCREASE OF TEMPERATURE OF WATER THROUGH A SUCTION PYROMETER

	Water Pressure, lb in²	Water Flow, gal h	Water Temp. Increase, °C			Uptake Wall Temp., °C	Preheat Temp., °C
			1 ft	2 ft	3 ft		
Air	20	360	11	21	28	1420	1135
W.G.	20	360	12	29	44	1530	
Air	45	600	9	15	20	1470	1075
W.G.	45	600	6	15	25	1565	

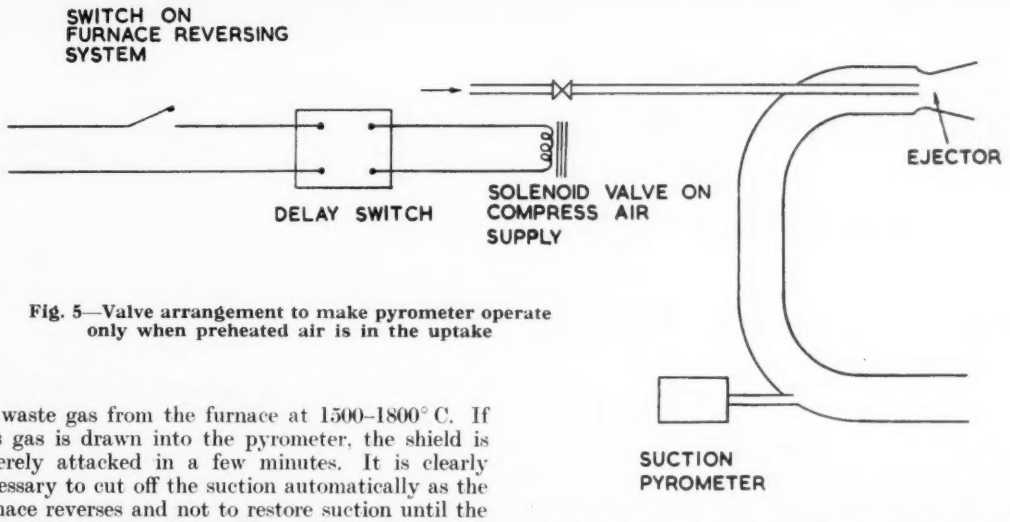

Fig. 5—Valve arrangement to make pyrometer operate only when preheated air is in the uptake

by waste gas from the furnace at 1500–1800° C. If this gas is drawn into the pyrometer, the shield is severely attacked in a few minutes. It is clearly necessary to cut off the suction automatically as the furnace reverses and not to restore suction until the air is again in the uptake. The cut-off is arranged to operate on the compressed-air line to the ejector. When the compressed air is cut off, the flow through the pyrometer falls to a small value owing to the difference in pressure inside and outside the uptake. This low flow has been shown to cause no blocking of the refractory shield.

One system to cut off the compressed air to the ejector is shown in Fig. 5. A mercury switch attached to a rocking member of the furnace reversing valve makes when the suction pyrometer is required to measure preheat and breaks during the waste-gas cycle. The mercury switch completes the circuit to a delay switch so that, after a known delay, the switch operates and then holds until the mercury switch opens.

A simpler and more direct methods can be adopted in which the steam pressure at the burner is used to operate the compressed-air valve.[6] This valve is arranged to open when full steam pressure is used to atomize the fuel, but to remain closed when dead-end steam is being used. This system automatically provides the 10-s delay, but a longer delay is difficult to arrange.

SUMMARY OF RECOMMENDATIONS AND CONCLUSIONS

(1) A suction pyrometer for preheated air in the uptake of open-hearth furnaces has been developed. A refractory shield is used inside a water-cooled probe with startling improvements in life and handling techniques.

(2) The accuracy of this arrangement in the conditions found in open-hearth furnace uptakes is equal or superior to conventional designs and is independent of the temperature of the walls. The error was found to be approximately 15° C at 1100° C.

(3) To obtain long life the suction should be switched off when there is waste gas in the uptake.

(4) A delay in switching the suction on after reversal gives time for the waste gas to be cleared from the checkers, which greatly increases the life of the shield. A delay of at least 10 s is desirable.

(5) For accurate operation the gas must be sucked at high velocity past the sheath and shields. A hot-gas velocity of 500 ft/s is ideal.

(6) The temperature of the gas leaving the probe is suggested as a guide to the gas flow in routine work.

(7) The error of the pyrometer was found to vary approximately inversely as the gas velocity. This enables a simple check to be made on accuracy during operation. The gas velocity should be halved. The fall in reading observed will be equal to the original error.

(8) For a given gas velocity and temperature it has been shown that the error remains constant for a considerable time and only becomes serious when two or more openings in the refractory shield are completely blocked.

(9) The pyrometer has been used in open-hearth uptakes for periods of three days without attention and at the end of this time the error was less than 30° C at 1100° C.

(10) Initial attention to the layout of the installation can save much trouble during use.

Acknowledgments

The authors wish to acknowledge the work of Mr. W. Platts of the Amalgams Co., Ltd., for the extruded sillimanite shield used with this pyrometer. Thanks are due to the management and staff of the Park Gate Iron and Steel Co., Ltd., the Steel Company of Wales Ltd., and John Summers and Sons Ltd., for facilities and help provided during works trials.

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Variations in the Structure across the Thickness of the Scale on Nickel Steels

By K. Sachs, Ph.D., M.Sc., A.I.M.

SYNOPSIS

The inner layers of the scales formed by various treatments on specimens of nickel steel were examined by a number of different methods. It was found that both the amount of metal in the scale and the overall Ni content pass through a maximum at some distance from the metal core; no nickel was found outside the dimensions of the original specimens, except in one case. The scale near the core consists of wüstite and metal enriched in nickel; the latter has a body-centred cubic structure (α) near the scale/metal interface and a face-centred cubic structure (γ) further out; in the zones where wüstite predominates all the nickel is found in the metallic particles. At some distance from the scale/metal interface, usually outside the original surface of the specimen, magnetite appears and gradually replaces the wüstite. At the outer surface of the scale, ferric oxide may be found.

A tentative diagram, showing the phases co-existing at 1200° C at various Ni contents and partial pressures of oxygen, was drawn, based largely on somewhat arbitrary estimates, but incorporating approximate experimental values for the Ni content of metal particles at various points in the scale. Such diagrams could be prepared for all temperatures, giving a model of Fe–Ni oxide equilibria.

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THE SCALE on nickel steels consists of three layers like that on iron and mild steel[1] and resembles it in other respects. Its characteristic feature is the presence of Ni-rich metal particles in the innermost layer. The amount of metal entangled in the scale depends on the Ni content and on the partial pressure of oxygen in the scale[2]; since there is an oxygen concentration gradient from the surface of the scale to the metallic core, there must also be a gradient of oxygen partial pressure and this should affect the distribution of metal across the thickness of the scale.

Previous work[3] has indicated a tendency for large particles to appear in the scale at some little distance from the interface and for relatively high Ni contents to be observed at points similarly remote from the interface. Some investigators have succeeded in stripping a Ni-rich film from the de-scaled core of an oxidized Ni steel and analysing it. Preece, Richardson, and Cobb[4] scaled 5% nickel steel for short periods in industrial atmospheres containing neither free oxygen nor unburnt fuel gases, but some traces of sulphur dioxide (0·04–0·064% SO_2); after removal of the outer scale the specimens were immersed in boiling (1 : 1) hydrochloric acid which dissolved the oxide and the small amount of oxide-sulphide eutectic between the metallic cores and the Ni-rich films, which, though porous, were strong enough to peel off. The Ni contents of three such films varied between 31·2% and 35·2%.

Similarly, Bénard and Moreau[5] oxidized a number of Ni–Fe alloys containing from 5% to 30% nickel in still air for varying periods at 950° C, and after knocking off the outer scale deposit subjected the remaining specimen to electrolytic treatments which gradually dissolved the surface material. The solutions were analysed and the Ni content at various levels, in that part of the scale where metal and oxide are intermingled, was deduced from the results and plotted against the thickness of scale dissolved. A porous film remained undissolved and peeled off when it had been sufficiently undermined by electrolysis. This film was richer in nickel than any other layer in the scale. The fact that material very rich in nickel failed to dissolve with the rest throws some doubt on the quantitative results, but the general impression that the Ni content increases at first gradually, and then steeply from the core of solid unaltered metal outwards into the layer of entangled metal and oxide, can probably be accepted. The same investigators used X-ray parameter[6] measurements to determine the Ni content of metal particles in the scale and obtained values as high as 95% Ni.

In the present work, spectrographic analysis was used for Ni determinations and the removal of the scale was carried out by linishing or filing. The Ni determination is less accurate, but the location of the samples is known more precisely than in the investigation quoted above. It was felt to be of interest to study the variation in Ni content, microstructure, and crystallographic phases across the thickness of the scale, in the hope of gaining information on the following points:

(*a*) Approximate distribution of overall Ni content across the scale

(*b*) Approximate distribution of metallic particles across the scale

(*c*) Correlation between Ni and metal particles and the various oxides present in the scale

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Dr. K. Sachs, formerly with The Mond Nickel Company, is now at the G.K.N. Research Laboratory, Wolverhampton.

(*d*) Crystallography of the metal particles, with an estimate of the Ni content from the parameter.

EXPERIMENTAL PROCEDURE

Three steels were used for the investigation. Their compositions are given in Table I. Specimens $\frac{1}{2}$ in. $\times$ $\frac{1}{2}$ in. $\times$ $\frac{3}{4}$ in. were scaled under various conditions, mostly in a gas furnace, and cooled rapidly on a large steel plate to preserve as far as possible the conditions stable at the scaling temperature. The atmosphere in the furnace chamber consisted of the products of combustion of Birmingham town's gas (which contains about 20 grains of sulphur per 100 ft^3) in sufficient excess air to maintain the desired temperature. Such an atmosphere can be regarded as strongly oxidizing and undoubtedly contains a concentration of SO_2 sufficient to accelerate oxidation.[4] The precise composition of the atmosphere around the specimen was not determined, but it is known[2] that the effect of less severe oxidation can be produced by covering the specimen with a small box, the top of which is welded to one side only, having a narrow gap to allow limited circulation of the atmosphere round the specimen; oxidation of the specimen consumes oxygen in the box and the partial pressure of oxygen in immediate contact with the specimen is diminished. After the oxidation treatment the scale layer on one face of the specimen was used for a survey of Ni content and phases present through the thickness of the scale. Successive layers of arbitrary thickness were removed by filing or linishing; the freshly exposed surface was sparked on the spectrograph and filings were collected for X-ray powder photographs. In X-ray surveys, precautions were taken that the filings collected from one face of the scaled specimen were not contaminated with material from adjacent faces. Microscopic examination was carried out on faces adjacent to those used for the spectrographic surveys. Correlation of results obtained on the scale formed on different faces of the same specimen is based on the assumption that under identical conditions of scaling comparable oxide deposits will be formed.

The success of the survey of the scale by removing successive layers depends on the adhesion of the scale to the steel core. In most cases it was found possible to take cuts of any desired thickness; very occasionally a portion of the scale crumbled and fell off. Some contamination of the freshly exposed surface is possible if the latter is porous and picks up powdered material.

The spectrographic determination of nickel in a scale containing Ni-rich metallic particles does not give correct Ni contents. Iron in the oxide gives a lower intensity in the arc than metallic iron; consequently the ratio of intensities of nickel to iron will be higher than the real ratio of contents and the spectrographic Ni figures are inevitably increased. This effect was studied by spectrographic Ni determinations on pressed powder samples consisting of iron oxides, nickel, and in some cases metallic iron.

For microscopic examination the specimens were mounted completely in Diakon to support the scale from all sides, and the whole mounts were then sectioned. Surveys of the amount of metallic material in the scale were carried out at a magnification of $\times$ 500 by means of a Zeiss projection microscope. The amount of metal present in the scale at various distances from the interface was estimated by projecting the structure on a screen and measuring the proportion of metal intercepted by a line, 100 mm long, ruled on the screen. An intercept of 1 mm corresponds to a linear dimension of 0·002 mm, or to 1% of the structure. The specimen was moved by measured amounts so that the number and length of the intercepts, as well as the proportion of the total intercept to the length of the line, could be plotted against the distance moved. The results cannot be considered quantitative, because of possible directional effects in the filigree, because the density of the metal is higher than that of the oxide and porosity is ignored entirely, and because at some distance from the interface, where individual particles are entangled in the scale, arbitrary movement of the specimen means that the line will often show zero interception, while deliberate setting of the line to intercept the particles visible in the structure will overestimate the quantity of metal present. Three readings were taken on each face of the specimen and mean curves were drawn through plots of all experimental readings. In this way a qualitative picture was obtained of the variation of the amount of metal at various depths in the scale.

Table I
COMPOSITION OF STEELS, %

Lab. Mark	C	Si	Mn	S*	P*	Ni
JXY	0·07	0·24	0·42	0·003	0·025	1·53
LTY	0·06	0·12	0·22	0·003	0·025	1·53
LTZ	0·04	0·08	0·15	0·003	0·025	2·92

* Nominal

Debye–Scherrer powder photographs were taken in a 9·0-cm dia. cylindrical camera using CoK_α radiation. Lattice parameters were obtained by plotting the measured values against the function $\frac{1}{2}$ ($\cos^2\theta/\theta = \cos^2\theta/\sin\theta$) as described by Taylor and Sinclair,[7] and extrapolated to 90°. Owing to the diffuseness of the high-order doublets of the austenitic metallic particles, their lattice parameters could not be obtained with a higher degree of accuracy than one part in 15,000, which corresponds roughly to an error of 2 at-% in Ni content in the portion of the Fe–Ni system under consideration.

EXPERIMENTAL RESULTS

Spectrographic Survey of Ni Content

To examine the effect of the partial oxidation of the sample on the spectrographic determination of the Ni content, standards consisting of mixed powders were prepared. Pieces of mild steel were scaled for 64 h at 1080° C, the oxide was removed, crushed with a pestle and mortar, and finally ground in a small ball-mill. Much of the mild steel had been oxidized completely and X-ray examination revealed

Table II

NICKEL CONTENT OF MIXED POWDER SAMPLES

Nature of Sample	Apparent Spectrographic Nickel Content						
	Ni, % added	NiI 3101·554 / FeI 3100·666			NiI 3414·765 / FeI 3413·135		
		1	2	3	1	2	3
Mild steel scale (85% Fe_2O_3, 10% Fe_3O_4)	1·5	2·4	2·6	—	1·9	—	—
Mild steel scale + 24·4% Fe powder (Fe content corresponds to FeO)	1·5	1·9	1·8	1·8	1·7	1·6	1·5
Scale heated *in vacuo* in presence of excess Fe powder (FeO)	1·5	2·1	2·3	2·3	1·9	1·8	2·0
FeO (as above) + 1·5% Fe powder	1·5	2·5	2·6	2·4	2·0	1·9	1·8
FeO + 3·18% of alloy powder (47·2% Ni, 52% Fe); equivalent to 1·5% Ni	1·5	3·2	2·6	2·2	2·2	1·9	1·9
FeO + 1·91% NiO, equivalent to 1·5% Ni	1·5	1·9	1·6	1·6	1·9	1·4	1·5
FeO	3	4·4	4·0	4·4	2·8	2·6	3·2

that the oxide consisted predominantly of ferric oxide, with about 10% magnetite and 5% wüstite. Some of this powder was treated *in vacuo* for 16 h at 1080° C; a larger quantity of iron powder was also present in the evacuated tube and, as expected, the oxide was reduced to wüstite; this was confirmed by X-ray examination after the sample had been ball-milled again.

These oxide powders were mixed with Ni, Fe, Ni–Fe alloy, and nickel oxide powders in the proportions indicated in Table II. Mixing was carried out after the samples were weighed out, by repeatedly spreading the powder out on a sheet of paper and piling it up into a small heap again; the samples were placed in small glass specimen tubes, packed into a tin which was gripped in the chuck of a lathe, and tumbled for 24 h.

The powder samples were pressed to a cylindrical shape, $\frac{1}{4}$ in. dia. and $\frac{3}{8}$–$\frac{3}{4}$ in. long, using pressures between 20 and 40 tons/in². The compacts were reasonably firm and no great difficulty was encountered in excitation. Three determinations were carried out on each specimen to check the adequacy of mixing. The apparent Ni contents were derived from normal steel standards (Spectrographic Standards, low-alloy steel series, Bureau of Analysed Samples, Middlesbrough). Two different line pairs were used and all the results are quoted in Table II.

The three readings for the same line pair in any sample are fairly consistent, suggesting that mixing of the powders was adequate, except perhaps in the case of the alloy powder addition. As was to be expected, 1·5% Ni powder added to wüstite gave a substantially higher apparent Ni content. The presence of 1·5% metallic iron, either in alloy form or as separate powder, did not appreciably effect the spectrographic Ni determination. Adding 1·5% Ni in the form of oxide (1·91% NiO) yielded an apparent Ni content appreciably below that for the same amount of metallic nickel; the mean value is a little above the real nickel content, i.e. the relative intensity of nickel lines is higher when both nickel and iron are oxidized than it is when both are metallic, probably because the less stable nickel oxide requires less energy for decomposition in the spark. More strongly oxidized scale gives substantially the same apparent Ni content as wüstite, but the addition of 24·4% metallic iron, which brings the overall Fe content to that of wüstite, raises the relative intensity of iron and thus lowers the apparent Ni content almost to the level of the actual addition.

While these trends could be observed in readings on both line pairs, the actual values of the apparent Ni content differ appreciably. Evidently the chemical and physical nature of the sample affects the interaction within the individual spectra of nickel and iron, and thus different line pairs will give different responses. This may also apply to any slight differences between scales and oxide powder

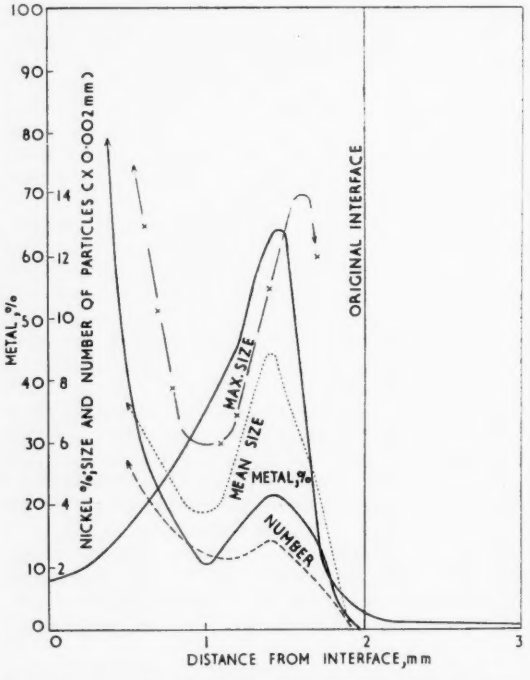

Fig. 1—Variation of structure with thickness of scale (*JXY* 16)

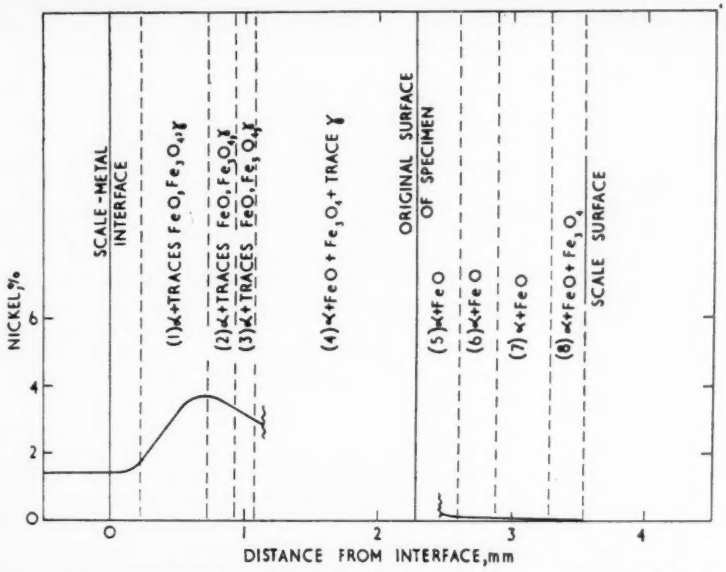

Fig. 2—Spectrographic and X-ray survey of reduced scale on *JXY* 42

compacts. It was not possible, therefore, to prepare a correction curve from which the real Ni content corresponding to any spectrographic determination could be derived. However, it can be concluded that the real Ni content will be between 60% and 85% of the apparent content.

On the basis of this assessment of the order of magnitude of the error introduced by the spectrographic determination of nickel in the scale, it is possible to consider the variation in apparent Ni content across the scale.

A specimen, *JXY* 16, of a 1½% Ni steel, was scaled for 8 h at about 1270° C under a 'protecting box' in a gas furnace. The variation in Ni content with distance from the interface is plotted in Fig. 1, together with the results of the micro-survey. The graph shows a sharp peak in the inner scale layer and the virtual absence of nickel beyond the confines of the original specimen. The curve agrees qualitatively with the observations of earlier workers[4, 5] and is typical of the distribution of Ni content in the scale of other specimens subjected to ordinary oxidation treatment in the course of this work.

Although the spectrographic results are 15–40% higher than the actual Ni contents, it can be concluded from Fig. 1 that the nickel concentration is by no means uniform throughout the scale layer. The spectrographically determined Ni content increases from 1½% in and near the metallic core to about 12% at the 'peak'.

The maximum degree of porosity observed in these scales is in the order of 50%; substantially higher porosity would be expected to cause crumbling and collapse of the scale. The Ni content would rise from 1½% to 3% with 50% porosity, and to 6% with 75% porosity. It would appear, therefore, that the peak in the Ni content cannot be attributed exclusively to porosity and that Ni atoms must have travelled over appreciable distances and in considerable quantities to produce a concentration of nickel of the order observed.

In order to confirm the reality of the peak, an attempt was made to prepare a thick scale as on the previous specimens and then to reduce it back so that the spectrographic survey could be carried out on substantially metallic material. It is known[8] that at high temperatures reduction by hydrogen of scale formed on steels occurs predominantly at the scale/metal interface and this zone was of primary interest. A back-reduction experiment was, therefore, carried out on specimen *JXY* 42. It was scaled in a gas furnace for 24 h at about 1250° C. It was then placed under a small box embedded in cast-iron turnings and re-heated for 24 h. In such an enclosed space the oxygen is soon used up and oxidation of the graphite in the packing material leads to the formation of carbon monoxide; equili-

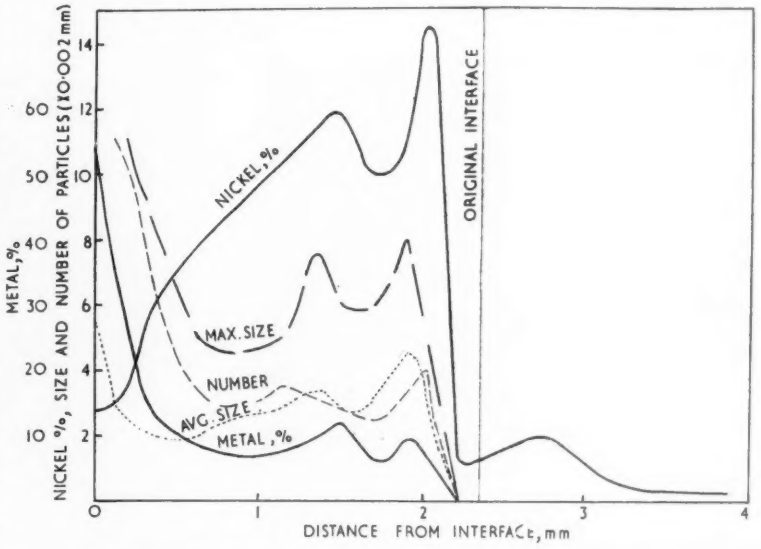

Fig. 3—Variation of structure with thickness of scale (*LTZ* 9)

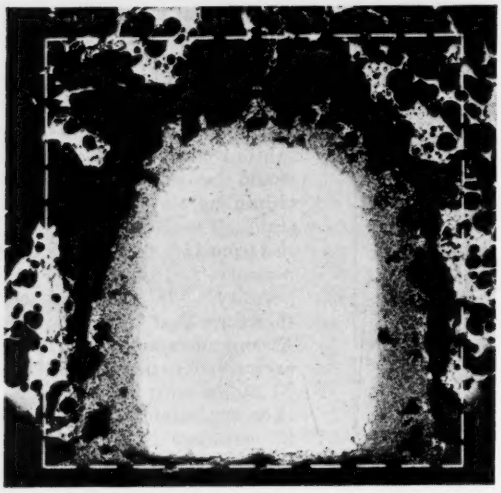

Fig. 4—Specimen *JXY* 18, exposed in a gas furnace at 1280° C for 7½ h × 5

brium between specimen and atmosphere is reached at a very low partial pressure of oxygen and much of the scale is reduced back to iron. The cold specimen appeared metallic throughout, although there were numerous oxide inclusions in the outer layers.

The progressive removal of the partially reduced scale and step-wise exposure of new levels for spectrographic Ni determinations was carried out by filing. Unfortunately, the deposit broke off after it had been filed down some way and an unknown thickness was lost. The curve of the spectrographic Ni content, shown in Fig. 2 together with the X-ray results, was qualitatively similar to that in Fig. 1, although the exact position of the points in the scale with different Ni contents was not known in the case of this specimen. However, there is no doubt that local accumulation of nickel has taken place, although its exact location is not established.

The effects of more complex oxidizing treatments on the distribution of nickel in the scale were also studied. Scaling treatments in which the temperature was suddenly altered led to the appearance of two nickel peaks. Specimen *LTZ* 9, for instance was subjected to a very complex treatment under a protecting box in a gas furnace, consisting of 4½ h at about 1200° C, 2½ h at 1000° C, 4½ h at 1200° C, 16½ h at 1000° C, 6 h at 1200° C, and rapid cooling from 1000° C. The intermediate heating and cooling was carried out as quickly as the furnace allowed. The plot of apparent Ni content against thickness of scale is shown in Fig. 3, together with the results of the microscopic examination. There are two sharp peaks within the original boundaries of the specimen and a possible shallow peak outside the original interface.

Micro-survey

The concentration of nickel at some distance from the core, which is indicated by the peak in the spectrographic survey curves, coincides with the accumulation of metal particles. This can be shown with particular clarity in specimen *JXY* 18, containing 1½% Ni, which was scaled without a box for 7½ h in a gas furnace at 1200° C. A cross-section through the specimen is shown in Fig. 4 with the original dimensions drawn in. The scale near the core is shown at a higher magnification in Fig. 5. The usual features will be observed; intergranular oxidation and filaments of metal in the scale, and thinning out to smaller discrete particles. Very large metal particles are found on the outside of the band consisting of entangled scale and metal. Further out, discrete, rounded metal particles are present in the scale. The structure of entangled scale and metal is shown in detail in Fig. 6.

The method of estimating the amount of metal embedded in the scale has already been described. The appropriate curves for specimen *JXY* 16 are plotted, together with the apparent (spectrographic) Ni content in Fig. 1. It will be noted that the quantity of metal in the scale reaches a maximum at

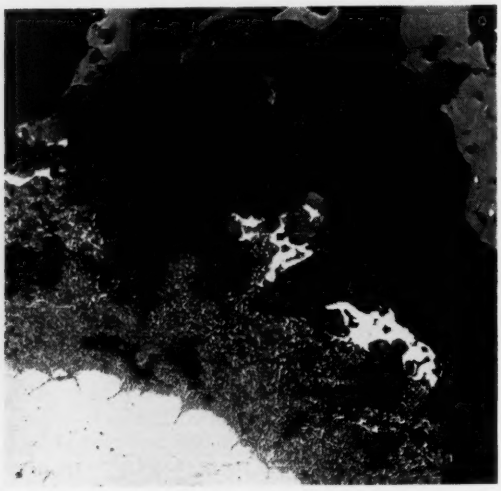

Fig. 5—Specimen *JXY* 18: scale near core of specimen × 20

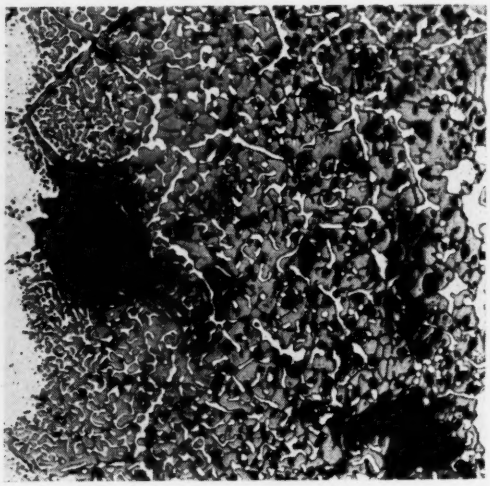

Fig. 6—Specimen *JXY* 18: metal filigree in scale × 50

Table III
PHASES PRESENT AT DIFFERENT LEVELS IN SCALE ON SPECIMEN *LTZ* 2

Sample No.	Distance from Interface, mm	Spectrographic Ni Content, %	Phases in Order of Predominance	Interfaces
1	−0·45–0	3	α + trace FeO + trace γ	Scale/metal
2	0 –0·3	3 – 5·5	α + FeO + γ	
3	0·3 –0·6	5·5– 7·0	FeO + α + γ	
4	0·6 –1·05	7·0– 8·5	FeO + γ + α	
5	1·05–1·6	8·5–10·3	FeO + γ + α	
6	1·6 –1·8	10·3–10·8	FeO + γ	
7	1·8 –1·95	10·3–11·1	FeO + γ	Nickel peak
8	1·95–2·25	11·1– 1·0	FeO + γ	
9	2·25–2·9	1·0–0	FeO + trace Fe_3O_4 + trace γ	Original surface
10	2·9 –3·95	0	FeO + trace Fe_3O_4	
11	3·95–4·55	0	FeO + Fe_3O_4 + trace Fe_2O_3	Scale surface

a distance corresponding to the peak on the curve for the Ni content. The curves for the number of particles and for the mean size of the metallic particles (in arbitrary units of 0·002 mm) follow that for the amount of metal present. The curve for the maximum size of metallic particles shows a gradual decrease from the metal core—which could only be represented as ' infinity '—reaches a minimum and then rises again. This agrees with the observation, illustrated in Figs. 4–6, that coarse metallic particles are found in the outside of the layer consisting of a metallic filigree embedded in the scale.

Figure 3 shows the curves for *LTZ* 9; the various curves for the metallic particles in the scale again follow the outline of the spectrographic survey. The zone containing metal particles did not at first appear to extend beyond the probable original boundary of the specimen, although the spectrographic analysis indicated a shallow peak in the Ni content. The highest Ni peak near the original surface of the specimen appears to coincide with an accumulation of fairly coarse metallic particles in the scale.

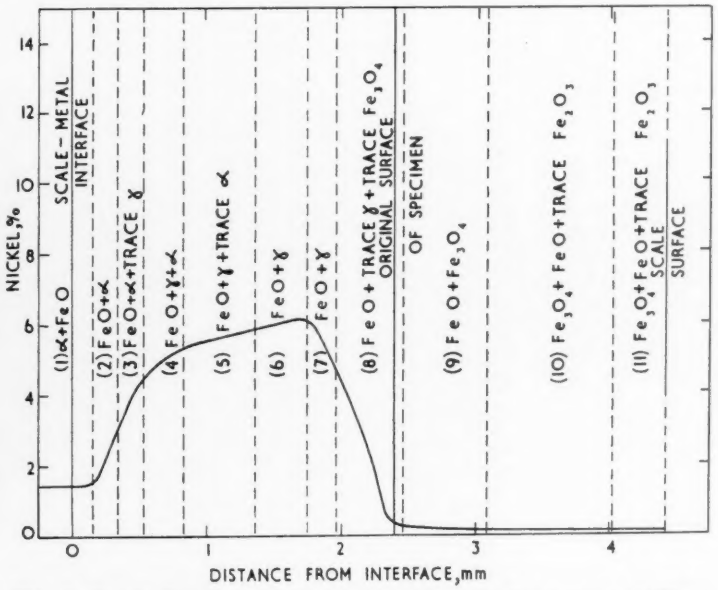

Fig. 7—Spectrographic and X-ray survey across the scale on *LTY* 1

X-ray Studies

The phases present at various levels in the scale on four specimens were examined by means of X-ray powder photographs. The results of the X-ray examination of the various samples taken from the scale on specimen *LTY* 1, scaled for 36 h at 1200° C under a protecting box, are summarized in Fig. 7, the zone from which each sample was taken being bracketed by dotted lines. The phases identified in each zone are quoted in order of predominance. The first sample was taken from the metallic core just below the scale; ferrite was found to predominate, although wüstite was also detected. This presumably corresponds to the zone of metal containing oxide globules. In the scale itself, wüstite is predominant and the metallic phase entangled in the scale changes from ferrite near the interface to austenite near the Ni peak. The outer scale layers contain magnetite free from nickel. Sample No. 8 on the far side of the Ni peak contains small amounts of both magnetite and austenite. It seems likely that the magnetite in this zone is formed by pro-eutectoid decomposition of wüstite; this is known to be very difficult to suppress,[9] and cooling on a steel block has evidently allowed the transformation to proceed. Towards the surface of the scale magnetite increases at the expense of wüstite and, in addition, traces of ferric oxide are to be found in the two outer samples where magnetite predominates.

The results for specimen *LTZ* 2 after a similar scaling treatment are collected in Table III. In general, they resemble those obtained on specimen *LTY* 1. The differences are of interest, however, and illustrate the effect of increase in Ni content. The metal core below the scale contains traces of austenite. This is considered to prove that the immediate scale/metal interface is enriched in nickel. Austenite gradually replaces

Table IV

PHASES PRESENT AT DIFFERENT LEVELS IN SCALE ON SPECIMEN *LTZ* 9

Sample No.	Distance from Interface, mm	Spectrographic Ni Content, %	Phases in Order of Predominance	Interface
1	−0·15–+0·05	2·8– 2·9	$\alpha + FeO + \gamma$	Scale/metal
4	0·35– 0·50	5·0– 7·0	$FeO + \gamma + \alpha$	
6	0·80– 1·10	8·5–10·0	$FeO + \gamma$ + trace α	
8	1·35– 1·55	11·5–11·5	$FeO + \gamma$	First peak
10	1·7 – 1·9	10·0–11·5	$FeO + \gamma$	
11	1·9 – 2·05	11·5–14·0	$FeO + \gamma$	Second peak
12	2·05– 2·6	14·0– 2·0	$FeO + \gamma$	Original surface; outer peak
13	2·6 – 3·05	2·0– 0·8	FeO + trace γ	
14	3·05– 3·25	0·8– 0·4	FeO + trace Fe_3O_4	
16	3·7 – 4·8	0	$Fe_3O_4 + FeO + Fe_2O_3$	Scale surface

ferrite in the metal particles in the scale, although the latter persists for some distance.

The results of the X-ray survey of specimen *JXY* 42 which was used for the back reduction experiment described above are summarized in Fig. 2; during the manipulation of the specimen a small portion of the scale was lost and this is indicated on the curve. The predominant phase throughout the specimen was ferrite. Some wüstite remained and both magnetite and austenite were found. The specimen was cooled slowly in a box filled with cast-iron turnings, and it is likely that the eutectoid decomposition of wüstite to ferrite and magnetite,[9] which takes place at 570° C under equilibrium conditions, had not been entirely suppressed. The presence of traces of austenite in material having a maximum overall Ni content of 4% indicates considerable micro-segregation.

The results for *LTZ* 9 are presented in Table IV. In the inner scale layer it is again wüstite which predominates, together with austenite corresponding to the Ni peaks. Close to the core, ferrite was formed as well as austenite, but the former gradually diminishes in amount towards the surface and disappears long before the Ni peak is reached. This specimen is unique in showing evidence of austenite beyond the original surface of the specimen. The portion of the scale corresponding to the small outer Ni peak consists of wüstite and austenite. Careful microscopic search of the appropriate fields of the specimen previously used for the micro-survey (Fig. 3) revealed tiny particles of metal embedded in the scale. They are too small and scattered to give a reading in the linear survey, but their presence confirms the X-ray results. A typical field, about 0·3 mm beyond the surface of the original specimen, is shown in Fig. 8.

The outermost X-ray sample, *LTZ* 9, No. 16, contains all three oxides. It seems very probable that three adjacent layers are incorporated in the sample, a surface of ferric oxide, an intermediate layer of magnetite, and some material from the body of the scale, consisting of magnetite and wüstite, the former probably resulting from pro-eutectoid decomposition of wüstite. The magnetite only exists at points where no austenite is present in the scale and where the Ni content is very low.

Iron–Nickel Oxide Equilibria

The phase equilibria of oxides are not fully illustrated by the usual type of equilibrium diagram because the variable partial pressure of oxygen introduces a degree of freedom which need not be taken into account when the system contains no gaseous component. Thus the iron–oxygen binary diagram does not state at what oxygen pressures the various phases are in equilibrium; it is a projection of a three-dimensional model with ordinates for oxygen content, partial pressure of oxygen, and temperature, on the plane representing oxygen concentration. The effect of partial pressure is illustrated in Fig. 9, where the logarithm of the partial pressure of oxygen is plotted against the reciprocal of the absolute temperature. This diagram represents a projection of the iron–oxygen model on the plane corresponding to partial pressure. It is based on the thermo-chemical equations for the oxidation and reduction of the various phases.[10] The dotted line for $Ni + O \rightarrow NiO$ is not part of this diagram; it should occupy a separate diagram, a projection of the nickel–oxygen model.

The equilibrium relations between iron, nickel, and oxygen cannot strictly be presented in three dimensions, but a model can be constructed which ignores oxygen concentration and has ordinates for nickel

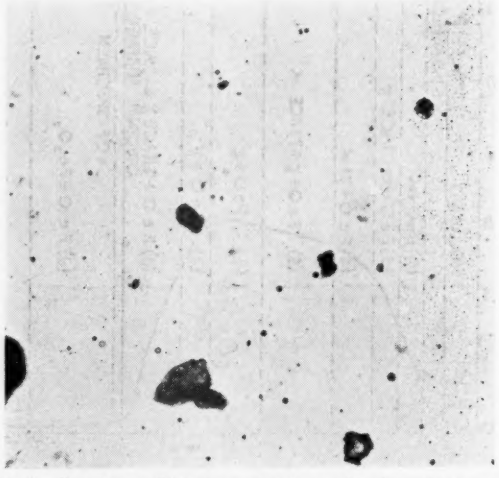

Fig. 8—Specimen *LTZ* 9: metal in scale about 0·3 mm outside the surface of the original specimen × 500

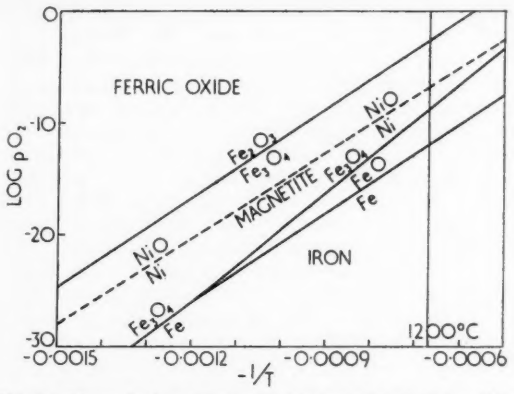

Fig. 9—Dissociation pressures of iron and nickel oxides

concentration, temperature, and the partial pressure of oxygen. Some of the experimental results obtained in the present work, together with the quantitative information contained in Fig. 10, make it possible to construct a hypothetical phase diagram showing the phases in equilibrium at various overall Ni contents and partial pressures of oxygen at any given temperature (Fig. 11). A series of such diagrams for various temperatures would form the three-dimensional model referred to above.

The scales examined in this work were cooled suddenly in the course of oxidation, while counter-current diffusion of iron and oxygen, oxidation of iron, and any other processes involved in the formation of the scale were actually in progress. The specimens are far from homogeneous and therefore the phases are by no means in equilibrium. Moreover, there is

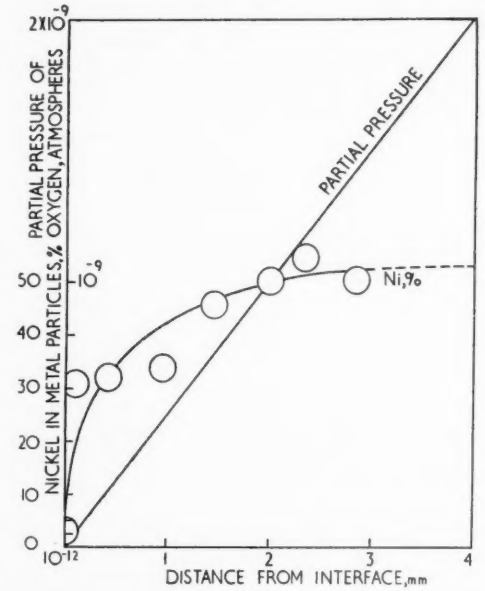

Fig. 10—Composition of metal particles and partial pressure of oxygen at various points of the scale on *LTZ* 9

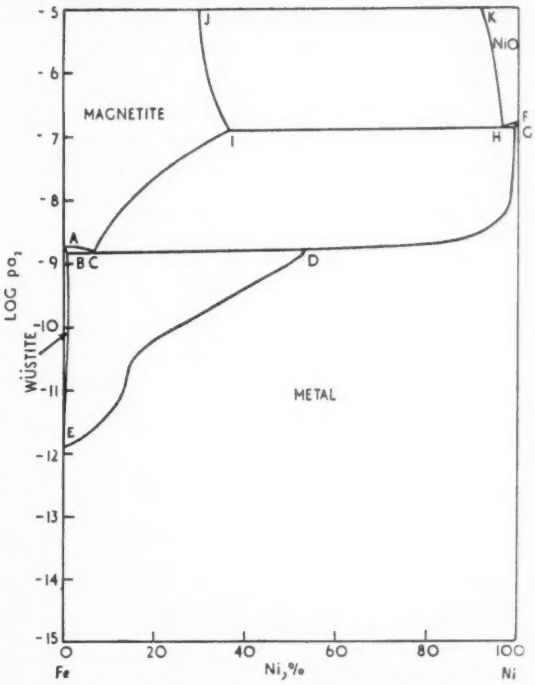

Fig. 11—Iron-nickel oxide diagram at 1200° C

a considerable variation in Ni content across the thickness of the scale. Nevertheless, diffusion is rapid enough at 1200° C to justify the assumption that locally the particles of the various phases are in a metastable relation with their immediate environment, which responds rapidly to any change in the environment. This means that variation in Ni content across the scale affects the amount of metal in the scale, while the composition of the metal depends exclusively on the partial pressure of oxygen. Preferential oxidation is assumed to keep the iron content of the metal at the equilibrium value corresponding to the partial pressure of oxygen in the scale. This assumption is in agreement with the conclusions drawn from previous experiments.[2]

Accordingly, it should be possible, by determining the Ni content of the metal particles at various levels in the scale, to plot the curve of equilibrium nickel content of the metal phase embedded in wüstite against the distance from the scale/metal interface, and to assume that the degree of approximation to the equilibrium curve depends on the rapidity of diffusion under the experimental conditions.

Some of the samples used for the qualitative X-ray survey of specimen *LTZ* 9 (Table IV) were used in the determination of the lattice parameter of the austenite in equilibrium with wüstite, and these were compared with published data. This could easily be carried out on a number of samples where the amount of free metal was high and the corresponding X-ray diffraction pattern was strong, but difficulties were encountered with samples furthest out in the

Table V

LATTICE PARAMETER DATA AND EQUIVALENT Ni CONTENT OF AUSTENITIC METAL PARTICLES EMBEDDED IN WÜSTITE

Specimen *LTZ* 9

Sample No.	Mean Distance from Interface, mm	Lattice Parameter, kX	Equivalent Ni Content, at-%
2	0·100	3·5805	30·8
4	0·415	3·5823	32·0
6	0·95	3·5854	33·7
8	1·45	3·5840	45·7
11	2·00	3·5786	50·0
12	2·35	3·5729	54·4
13	2·84	3·5784	50·2

scale where only small traces of metal were found in the wüstite. The problem was solved to a limited extent by grinding the scale and separating the wüstite from the austenite, which was sufficiently rich in nickel to be strongly ferro-magnetic, with a magnet; nevertheless, in some samples the amount of metal was still inadequate to give satisfactory X-ray diffraction patterns from which parameters could be accurately determined.

The results of the lattice parameter measurements of the austenite are given in Table V. Since the lattice parameters of some of the samples lay near the maximum in the parameter/composition curve of the Fe–Ni system,[11] it was possible to attribute two discrete Ni contents to them. The correct values for the Ni content were selected on the reasonable basis that Ni content increases continuously with the distance from the interface and these values are plotted in Fig. 10 against the distance from the interface of the sample used for the determination.

It will be noted that the highest Ni content recorded in Table III is 54·4%, and that the graph in Fig. 10 shows a value of about 50% Ni at a point 3 mm from the scale/metal interface, i.e. at the farthest point where metal was still detected. Moreau and Bénard[6] have obtained much higher Ni contents in similar experiments. Ni–Fe alloys containing 5%, 10%, 20%, and 30% nickel were heated for several hours at 850°, 950° and 1050° C. After 5 h at 1050° C, parameter determinations on the metal " immediately underlying the oxide " on a 30% Ni alloy indicated a Ni content of 95%. It is recognized that the wüstite layer extends beyond the zone containing metal particles. Thus, at the temperature of the scaling treatment, there is an appreciable thickness of wüstite between the outermost metal particles and the boundary between wüstite and magnetite, and the partial pressure of oxygen at which wüstite is in equilibrium with magnetite is appreciably higher than that of the wüstite actually in contact with metal. The Ni content of metal in equilibrium with wüstite of the maximum partial pressure of oxygen at which this phase can remain stable cannot therefore be determined from the available samples. The general shape of the curve in Fig. 10 suggests, however, that extrapolation would not lead to Ni contents far in excess of 50%, and the value used in the hypothetical phase diagram in Fig. 11 is of that order. It may be that steel *LTZ* with only 3% nickel was not suitable for the determination of the equilibrium Ni contents of the metal in the scale. It is possible, however, that the Ni-rich particles found by Moreau and Bénard were in equilibrium with magnetite and not with wüstite. Their experiments were carried out under more severely oxidizing conditions and at lower temperatures than those described in the present work. Both these factors would favour magnetite as against wüstite.

The partial pressure of oxygen falls off in the direction of the metal core. To a first approximation, it would seem likely that the variation is linear within any given phase field with a sharp change in slope at phase interfaces. The straight line for the increase in partial pressure of oxygen from the core to the magnetite/wüstite interface has been plotted in Fig. 10. The partial pressure of oxygen at the interface itself is not likely to be much higher than the value of $1 \cdot 26 \times 10^{-12}$ atm which applies for pure iron (Fig. 9). Since the actual value must be a little higher than this, an arbitrary value of $1 \cdot 5 \times 10^{-12}$ is used without introducing any appreciable error. The extent of the wüstite zone at 1200° C cannot be established with any accuracy from Table IV because pro-eutectoid magnetite has penetrated into the wüstite layer in the course of cooling. The presence of wüstite in X-ray sample 16 indicates that the wüstite/magnetite interface at 1200° C must have been located within this sample, and its actual site will be assumed, somewhat arbitrarily but not unreasonably, to be 4·0 mm from the metal/wüstite interface. If it is accepted that the solubility of nickel in wüstite is negligible, so that the straight line for partial pressure in Fig. 10, which is based on values for wüstite formed on pure iron, is valid for wüstite co-existing with nickel, the graphs in Fig. 10 can be combined to plot the variation in the nickel content of metal particles against the appropriate oxygen pressure to yield a curve relating the composition of the metallic phase to the partial pressure of oxygen in the wüstite. This is incorporated (curve *ED*) in the tentative Fe–Ni oxide diagram in Fig. 11, where the partial pressure of oxygen is plotted against the Ni content.

It has been possible to provide experimental evidence for the validity of some features of this Fe–Ni oxide diagram. The curve for the composition of metal in equilibrium with wüstite has been drawn on the basis of rough quantitative data; the assumptions made in plotting this portion of the diagram are recapitulated below:

(*a*) Although there are overall variations in the concentration of iron, oxygen, and nickel, the metal particles are in a metastable relation with the oxide immediately surrounding them and this relation responds rapidly to changes in the partial pressure of oxygen.

(*b*) The partial pressure of oxygen varies approximately linearly across the thickness of any scale layer consisting of the same phases.

(*c*) The oxygen pressures at equal depths in the scale are the same, except in the immediate neighbourhood of irregularities in the scale/metal interface.

(*d*) The solubility of nickel in wüstite can be neglected, so that partial pressures at the scale/wüstite

and wüstite/magnetite interfaces, derived from Fig. 9, i.e. from pure iron oxides, can be applied in spite of the presence of nickel in the alloy.

If Moreau and Bénard's[6] figure of 95% for the Ni content of metal particles applies to equilibrium with wüstite, point *D* should be at 95% and the rest of the diagram drawn accordingly.

In addition to curve *ED*, the remainder of the tentative diagram in Fig. 11 is based on the following:

(i) The equilibria for the pure metals at 1200° C (points *A*, *E*, and *F*) are known (*see* Fig. 9).

(ii) Wüstite is known to dissolve very little nickel (point *B*).[12]

(iii) The existence of a ferro-magnetic phase, $NiO.Fe_2O_3$,[13] which is probably part of a series of solid solutions, indicates that the solubility of nickel oxide in magnetite must be considerable. It follows that the three-phase equilibrium *C*, between magnetite, wüstite, and metal, should occur at an oxygen pressure below that for the wüstite–magnetite transformation *A*, in pure iron oxide; otherwise the wüstite phase would hold more nickel in solution than the magnetite in equilibrium with it. According to Fig. 10 the last traces of metal are surrounded by wüstite having an estimated partial pressure of oxygen of about $1 \cdot 4 \times 10^{-9}$ atm. Clearly the three-phase equilibrium must lie between this value and that corresponding to point *A*, $1 \cdot 99 \times 10^{-9}$. In plotting Fig. 11 a value of $1 \cdot 5 \times 10^{-9}$ was used.

(iv) It has been assumed that no Ni_3O_4 phase, and no intermediate oxides other than the magnetite spinel series Fe_3O_4—$NiO.Fe_2O_3$—$(Fe.Ni)_3O_4$ are formed.

(v) The solubility of iron in nickel oxide is not known and therefore the corresponding line *HK* has been arbitrarily drawn.

(vi) Fairly pure nickel can be formed by the reduction of mixed oxides. It follows that the three-phase equilibrium *H*, between metal, nickel oxide, and magnetite, lies very close to the nickel ordinate so that it is relatively unimportant whether it takes place at a higher or a lower pressure than the oxidation of nickel. In Fig. 11 it is drawn in at a lower pressure (line *GHI*) on the assumption that small as well as large additions of iron to nickel lower the latter's stability against oxygen.

(vii) For the same reason, the iron content of the metal in equilibrium with magnetite (line *GD*) has been assumed to be low and the boundary line of the metal field has been drawn very steep at oxygen pressures immediately below the three-phase equilibrium *H*.

Thus, three points on the diagram (*A*, *E*, and *F*) are firmly established; the general shape of the curve *ED* is based on experimental evidence, the limitations of which have been indicated. The rest of the diagram, including the oxygen pressures of the three-phase equilibria *GHI* and *BCD*, and the composition corresponding to points *B*, *D*, *G*, and *H* are qualitative estimates, while the compositions of points *C*, *I*, *J*, and *K* are quite arbitrary. Nevertheless, the diagram indicates roughly the equilibrium conditions of the various phases at 1200° C and shows the kind of structures to be expected in oxide mixtures and scale of various compositions at different partial pressures of oxygen; it might also serve as a guide in the establishment of an accurate diagram for real equilibrium mixtures, which might not only be of academic interest, but would assist in the construction of a nickel–iron–oxygen ternary diagram.

CONCLUSION

The Fe–Ni oxide diagram in Fig. 11 relates the Ni content at any point in the scale to the oxygen pressure of the scale at that point. A vertical line on this diagram represents varying oxygen pressures and a constant Ni content, and should therefore represent the changes across the thickness of the scale on a steel of the appropriate Ni content. Actual surveys of the variation in Ni content indicate that in the process of oxidation there is a gross movement of nickel towards zones corresponding to the peaks on the experimental curves. This does not affect the composition of the particles in the scale, which depends on the oxygen concentration in the oxide; it does affect the amount of metal embedded in the scale which has been shown to vary in the same way as the spectrographic Ni content. The mechanism of this gross movement of nickel through an oxide in which nickel is practically insoluble and in which nickel oxide is unstable remains to be elucidated.

Although nickel has been shown to move over appreciable distances, there was only one specimen in which nickel was found in that part of the scale outside the dimensions of the original specimen. In this case the scaling treatment was very complicated and involved repeated temperature fluctuations. This would tend to modify the normal layer structure and might favour the formation of magnetite which could take nickel into solution. In any subsequent transformation of magnetite to wüstite, nickel would be precipitated in the form of metal particles.

Acknowledgments

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The Nature of Ageing of Binary Iron–Chromium Alloys Around 500°C

By R. O. Williams, M.Sc., Ph.D., and H. W. Paxton, M.Sc., Ph.D.

SYNOPSIS

An investigation of ageing (475° C embrittlement) of Fe–Cr alloys has been carried out using electrical resistance, hardness, magnetic measurements, and X-ray diffraction. On the basis of this work it is concluded that a miscibility gap exists below 600° C and is joined by one or two eutectoid reactions to the sigma-forming regions. Chemical and/or magnetic energies may be responsible for the gap and perhaps account for the odd shape.

The gap results in the precipitation of a Cr-rich phase which is always coherent with the matrix. As a result of this coherency, both the matrix and precipitate are isotropically strained to a common lattice parameter. Since no loss of coherency occurs, the alloys do not over-age and particles larger than 200 Å were not found. Because of the nature of the strains, it is proposed that the particles interact with the hydrostatic component of edge dislocations in contrast to shear interaction. 1267

AN EXPERIMENTAL INVESTIGATION has been made of the nature of the ageing of Fe–Cr alloys in the temperature range of 400–550° C. This ageing phenomenon has been known as '475° C embrittlement' of ferritic stainless steels. Such a name arose, no doubt, from the very brittle nature of such materials for no apparent reason when aged in this temperature range. This study has shown that the phenomenon is one of ageing or age-hardening in more or less the usual sense. This problem is of interest for two reasons: this ageing imposes severe limitations on the practical utilization of such alloys and the basic nature of this ageing has not been clearly resolved in spite of extensive investigations.

The change which these materials undergo on ageing in this temperature range can be described briefly. The room-temperature ductility and impact strength decrease to essentially zero and the hardness and strength increase markedly. The increases in physical properties are, however, useless because of the extreme brittleness. The ageing is accompanied by decreases in electrical resistivity and corrosion resistance and an increase in Curie temperature. A significant quantity of heat is also released during ageing. The changes which can be shown by means of X-ray diffraction or microstructural methods are somewhat controversial, but are slight in any case. Ageing effects can be removed completely by holding the materials at about 600° C for a short time. The most important new phase identification was a chromium-rich precipitate resulting from the ageing (Fisher *et al.*[1]). The more important investigations and reviews of the subject are given below:

Bandel and Tofaute,[2] Becket,[3] Fisher, Dulis, and Carroll,[1] Heger,[4] Hochmann,[5] Imai and Kumada,[6] Krivobok,[7] Lena and Hawkes,[8] MacQuigg,[9] Masumoto, Sainto, and Sugihara,[10] Newell,[11] Riedrich and Loib,[12] and Tagaya *et al.*[13]

Three theories have been advanced to explain this ageing. It has been supposed that the presence of some minor phase as an oxide, nitride, phosphide, or carbide is responsible. Other investigators have believed that ordering is the process responsible for the changes. The most popular theory, however, is the one which supposes that the ageing is connected with the tendency to form σ-phase: more explicitly, it is supposed that the ageing is a result of the formation of a transition lattice prior to the formation of equilibrium sigma. There is almost no direct evidence in support of the first two theories, while certain similarities between this system and the classical system (Al–Cu), give considerable support to the last theory. However, it is necessary to suppose that the high-chromium phase is the transition structure and this is the interpretation given by its discoverers and by Lena and Hawkes.[8]

This study was undertaken to provide additional information on this ageing process. Many new details have been discovered and an entirely new interpretation of the phenomenon is given. A previously unrecognized type of age hardening is shown to occur, and it suggested the development of certain new ideas of the mechanism of hardening.

EXPERIMENTAL PROCEDURES

In this work a wide range of purities and compositions was used; these were given several different mechanical and thermal treatments prior to ageing. The processes of ageing and recovery were followed by hardness, resistivity, and magnetic measurements, and considerable X-ray diffraction and microstructural work was done. Normally, isothermal ageing was used, followed by recovery during slow heating which caused the precipitate to go back into solution.

The alloys which were used in this study are listed in Table I. The first seven pairs were laboratory induction melts made by Allegheny Ludlum Research

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Dr. Williams formerly Allegheny Ludlum Research Fellow of the Carnegie Institute of Technology, Pittsburgh, Pa., is now Senior Research Metallurgist at the Cincinnati Milling Machine Co., Cincinnati, Ohio, U.S.A.

Dr. Paxton is Assistant Professor of Metallurgy at the Carnegie Institute of Technology.

This work was done as partial fulfilment of requirements for Ph.D. Degree for the first author.

Table I

ANALYSES OF ALLOYS: VALUES IN wt-%

Alloy No.	Cr	Mn	Si	N_2	C	P	S
83	17·74	0·49	0·65	0·021	0·033	...	0·011
83*V*	17·37	0·23	0·60	0·0015	0·016	...	0·006
24	30·24	0·45	0·22	0·19	0·028	...	0·011
24*V*	29·92	0·20	0·23	0·002	0·019	...	0·004
79	30·64	0·50	0·50	0·38	0·024	...	0·013
79*V*	28·55	0·23	...	0·005	0·012	...	...
82	30·74	0·54	0·29	0·29	0·020	...	0·014
82*V*	30·05	0·26	...	0·0015	0·016	...	0·005
90	30·10	0·62	0·61	0·039	0·025	...	0·012
90*V*	29·46	0·41	0·61	0·003	0·012	...	0·006
30	41·27	0·38	0·27	0·11	0·021	...	0·015
30*V*	40·12	0·25	...	0·0025	0·029	...	...
41	52·72	0·30	0·23	0·081	0·041	...	0·011
41*V*	50·58	0·18	0·19	0·0025	0·014	...	0·005
46	46·24	...	0·085	0·004	0·015	...	...
46*V*	...	...	0·094	0·011	0·024	...	0·004
*K*314	14·81	Nil	Nil	0·0022	0·014	About 0·008	About 0·016
*L*681	20·55	Nil	Nil	0·003	0·013	About 0·008	About 0·016
*L*684	23·04	Nil	Nil	0·005	0·008	About 0·008	About 0·016
*K*396	37·74	Nil	Nil	0·0039	0·016	About 0·008	About 0·016
*K*590	55·70	0·01	Nil	0·0034	0·020	About 0·008	About 0·016
70	68·66	...	...	...	0·06	...	...
80	79·50	...	...	...	0·06	...	...

Laboratory for this study. Alloy 46 was supplied by E. J. Dulis of United States Steel, the next five were furnished by W. O. Binder of Electro Metallurgical Company, and the final two came from A. H. Sully of Fulmer Research Institute. The last eight alloys were vacuum-melted alloys made from pure stock, and are generally equivalent to the best used by previous investigators. The second listing of an alloy followed by a '*V*' refers to a special vacuum treatment which is discussed below.

All hardness measurements were made using a Vickers Diamond Pyramid Hardness Tester and a 10-kg load. Normally, the same sample was used for a complete series of tests where the sample was re-aged for an additional increment of time. At least five readings were made after each interval, and this would normally give indications of changes as small as five to ten numbers (2%), unless copious mechanical twinning occurred, as normally happened with higher-Cr specimens.

During fabrication, most of the materials were heated in air. Ageing was carried out either in lead pots or in an inert atmosphere. The only important thermal treatment so far as composition goes was the vacuum annealing homogenization, as denoted by '*V*' in Table I. This process consisted of electrically heating the material in the form of $\frac{1}{8}$-in. rods in vacuum for several hours at 1050° C, in argon at 1200° C for 24 h and finishing in vacuum at 1050° C for 20 h. As shown by the analysis, this treatment gave a great reduction of nitrogen and a small reduction of carbon, manganese and sulphur, and probably of phosphorus and oxygen. The reduction of minor phases in the microstructure was very great. However, some minor phase or phases were put into solution, as evidenced by later microscopic examination.

The resistivity measurements were made by determining the voltage drop across specimens of known size when a current of 1·000 A (accurate to about 0·1%, constant to 0·001%), was passed through them. Readings could be made such as to detect changes of 0·002 Ω-cm. The experimental points, however, varied from the most probable value by about three times this figure for reasons not completely known, but the results were accurate enough for the purpose. Because of the large temperature coefficient of resistance of these alloys, the furnace used for the ageing had to be controlled closely. By suitable design, it was possible to obtain fluctuations less than 0·1° C and drifts of about 1°, which proved satisfactory.

The magnetic measurements were performed by the circuits and arrangement illustrated in Fig. 1. The field could be determined by either going above the Curie temperature or by removing the sample. Apparently, based on experimental results, the small gaps at the ends of the sample introduce no detectable demagnetization force. Measurements were made with fields of 650, 1400, and 2200 oersteds, but as the smallest field saturated the sample only these results

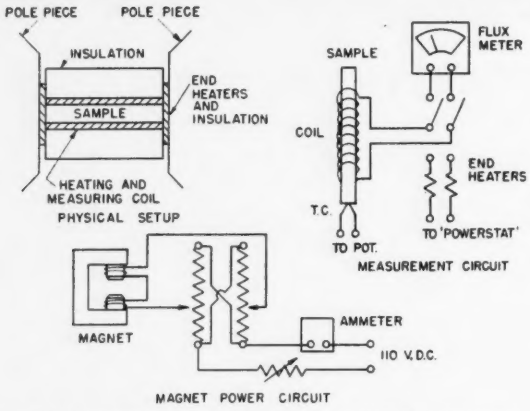

Fig. 1—Apparatus and circuits for magnetic measurements

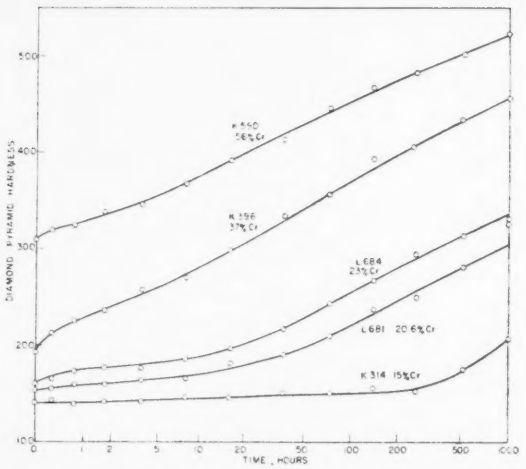

Fig. 2—Hardening characteristics of high-purity Fe–Cr alloys during ageing at 475° C

have been included. Ageing was accomplished by removing the sample and placing it in a lead pot.

EXPERIMENTAL RESULTS

Isothermal Ageing

The changes in physical properties which result on isothermal ageing of these Fe–Cr alloys are given in Figs. 2 to 13 and in Table II. In most of these figures the time scale is modified by adding 1 h to the actual time, so that 0–999 h covers three cycles of log paper.

Figure 2 shows the hardness changes of a series of high-purity alloys which has been received from the Electro Metallurgical Company. To reduce the scatter in the hardness readings, these alloys had been hot-rolled at 875°C by about 50%. This caused about 25% of the material to recrystallize, but there was no evidence during this study that deformed and recrystallized material behaved differently. Figure 3 gives data from certain other alloys which were less pure, and it will be noted that they fit the same pattern. It might be noted that Alloy 41 is the one which was used to make magnetic measurements. Alloy 90 had been hot-rolled and Alloy 79 was aged as a single crystal and in a magnetic field, but no significant differences were found. The smaller scatter from hot-deformed alloys as compared to others is apparent.

While no detailed study has been made of the hardening of cold-worked materials, it has been established that the numerical increase in D.P.N. for such materials is significantly less than for recrystallized materials after 1000 h at 475° C. This was due in part to mechanical recovery during ageing, as clearly demonstrated by the decrease in line widths in Debye–Scherrer patterns. Such alloys had still not recrystallized at 550° C when given the treatment noted in Fig. 8. Also, Alloy *L*681 (23% Cr) failed to recrystallize in 90 days at 500° C after a 95% cold reduction. From this it can be concluded that the presence of the precipitate does not promote recrystallization and may, in fact, retard it.

Becket[3] and Lena and Hawkes[8] have reported high-purity alloys which showed a very slight tendency to age. Lena and Hawkes have concluded that either nitrogen must be present and precipitate out or else the alloys have to be deformed. While there may have been justification for this conclusion from their work, the present work does not support this conclusion. An alternate explanation which is yet unproved is that thermal treatment prior to ageing is very important. That prior treatment has an effect has been stated by Samans[14] without details and shown by Lena.[15] To check this possibility a series of samples of Alloy 82 after vacuum annealing were held for 1 h at temperatures between 530° and 800° C, quenched in oil, and then aged at 475° C. The data are plotted in Fig. 4. It should be noted that some slight amount of a minor phase may have precipitated and given rise to some of the effects shown, but this is not likely in that all the samples were held 1 h at 800° C after the vacuum treatment, and this should have precipitated this

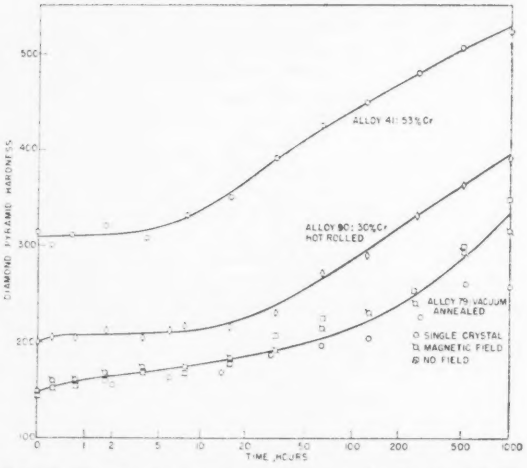

Fig 3—Hardening characteristics of Fe–Cr alloys during ageing at 475° C

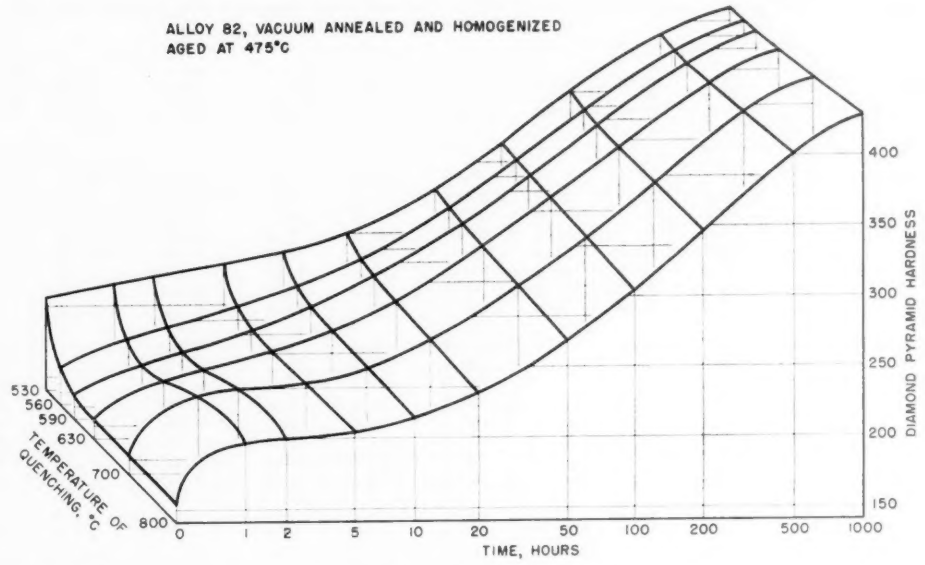

Fig. 4—Effect of quenching temperature on the hardening characteristics of a 30% Cr–Fe alloy during 475° C ageing

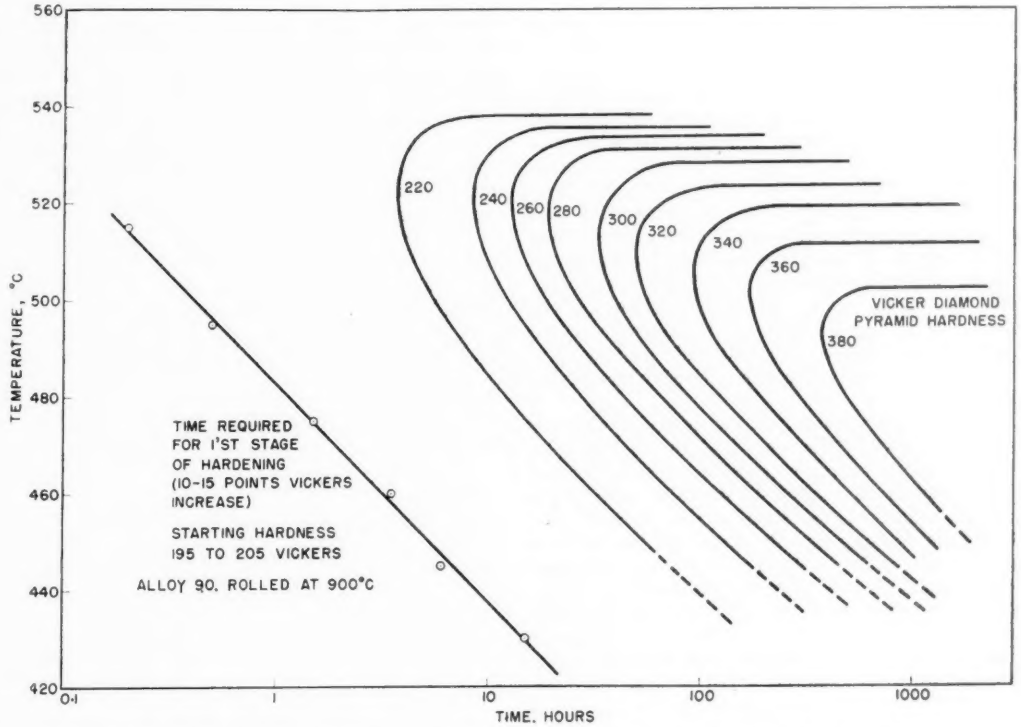

Fig. 5—Time/temperature dependence of hardness of a 30% Cr–Fe alloy during ageing

Table II

SUMMARY OF RESISTIVITY CHANGES OF Fe–Cr ALLOYS RESULTING FROM AGEING 1000 h AT 475° C

Starting State	Alloy No.	Cr content, wt-%	Initial 25° C Resist.	Final 25° C Resist.	Initial 475° C Resist.	Final 475° C Resist.	Dec. % in 475° C Resist.	Initial Temp. coeff. at 25° C, % per ° C	Final Temp. coeff. at 25° C, % per ° C	Re-solution Temp. with Slow Heating, ° C
Cold worked	83	17·7	62·1	59·4	99·8	95·5	4·3	0·178	0·146	...
	24	30·2	57·5	54·7	100·0	90·6	9·4	0·205	0·170	...
	79	30·6	60·4	59·5	102·5	94·1	8·2	0·201	0·144	...
	82	30·7	60·2	57·5	103·4	93·7	9·4	0·185	0·146	...
	90	30·1	61·1	57·9	97·5	89·1	8·6	0·164	0·139	...
	30	41·3	61·7	55·6	103·6	90·0	13·1	0·196	0·152	...
	46*	46·3	55·9	52·5	99·3	86·0	13·5	0·246	0·169	...
	41	52·7	66·0	58·1	103·6	90·5	12·6	0·223	0·145	...
Recrystallized	83	17·7	60·8	...	100·4	96·8	3·6	0·160	...	527
	24	30·2	56·6	...	100·0	91·8	8·2	0·171	...	541–58
	79	30·6	58·6	...	102·0	94·6	7·3	0·179	...	541–55
	82	30·7	59·5	...	103·1	95·0	7·8	0·193	...	541–65
	90	30·1	59·6	...	97·1	90·0	7·3	0·163	...	541–62
	30	41·3	59·5	...	102·0	91·3	10·4	0·201	...	553
	46	46·3	55·5	...	99·0	86·5	12·6	0·229	...	558
	41	52·7	62·7	...	104·4	92·0	11·9	0·196	...	553
Vacuum annealed	83	17·4	62·0	61·5	105·2	103·0	2·2	0·161	0·150	518
	24	29·9	54·8	54·3	100·4	92·5	7·9	0·229	0·170	544–53
	79	28·6	61·5	60·3	104·0	96·7	7·0	0·188	0·151	539–53
	82	30·0	57·7	55·2	104·8	89·5	14·6	0·224	0·167	546–53
	90	29·5	64·8	62·7	106·2	97·2	8·5	0·197	0·135	537–53
	30	40·1	58·0	57·8	100·6	93·0	7·5	0·213	0·162	544–51
	46	46·2	57·8	56·6	114·1	102·5	10·2	0·248	0·176	560
	41	50·6	54·7	53·2	86·0	79·0	8·2	0·226	0·177	546

*Recrystallized

phase. The quenching rate was fairly fast, although oil was used, since the samples were $\frac{1}{8}$-in. rods.

In spite of rather extensive data by previous workers, it was not possible to construct a transformation/temperature curve in terms of physical parameters such as hardness. For this reason, samples of hot-rolled Alloy 90 were aged at different temperatures and the results are assembled in Fig. 5. Two points should be noted. The hardness does not decrease at any time for isothermal ageing, even when the total time is ten times that required for maximum hardness; the final hardness is reached sooner the higher the temperature. The completion of the first stage of ageing (*see* Fig. 13) is shown to give a straight line parallel to the underside of the knee. It corresponds to an apparent activation energy of 55,000 cal/mol.

Extensive work was done on the resistivity changes of the alloys from Allegheny Ludlum in the cold-worked (60% reduction), recrystallized, and vacuum-annealed conditions. Alloy 46 was also used in the last two conditions. Because of the marked similarity of the changes for all alloys, the results have been condensed into Table II. The principal points which are shown are that the decrease in room-temperature resistance is less than that at high temperatures, that the decrease increases with chromium content within the range studied, and that the change in temperature coefficient is small at high temperatures and larger at lower temperatures as a result of ageing.

An example of how the resistance changes as a function of time is shown in Fig. 6 for Alloy 79. The results for the other alloys were very similar. The small vertical displacements result from different specimens and are not significant. Except for the difference in the initial part, the three curves are virtually parallel. The difference in the initial part is a result of the differences in cooling rate prior to ageing. The cold-worked sample was cooled fastest and shows the most pronounced initial effect, while the recrystallized sample was cooled from 1000° to 300° C in about 1 h and shows the least effect. The vacuum-annealed sample had an intermediate cooling rate. This type of behaviour is general and has been studied in some detail.

It has been shown in Table II that the change in resistance at elevated temperatures is greater

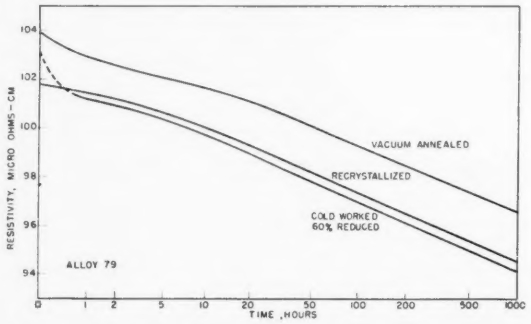

Fig. 6—Resistivity changes for a 30% Cr–Fe alloy aged at 475° C with different initial treatments

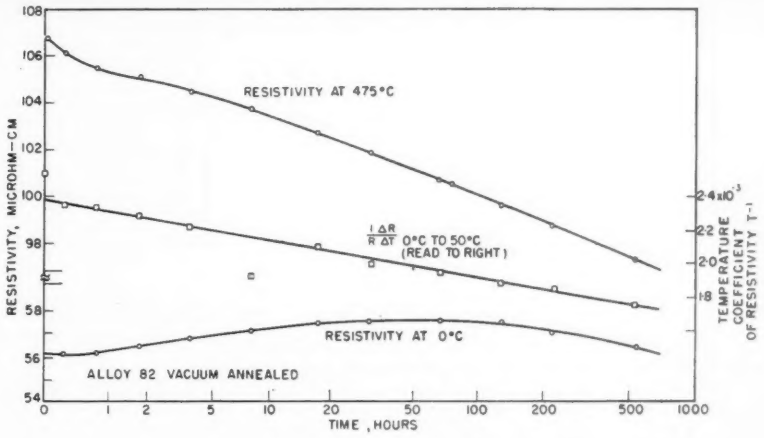
RESISTIVITY AT 475°C
$\frac{1}{R}\frac{\Delta R}{\Delta T}$ 0°C TO 50°C (READ TO RIGHT)
RESISTIVITY AT 0°C
ALLOY 82 VACUUM ANNEALED
RESISTIVITY, MICROHM-CM
TEMPERATURE COEFFICIENT OF RESISTIVITY T⁻¹
TIME, HOURS

Fig. 7—Changes in resistivity at 0° C and 475° C of a 30% Cr–Fe alloy during ageing at 475° C

than that at low temperatures. To study this effect as a function of ageing time, a sample of Alloy 82 which had been given a vacuum anneal was placed in a 'Vycor' tube sealed at one end. The necessary connections were made to measure the electrical resistance and the thermocouple was peened into the sample. Helium was used inside to promote heat transfer and protect the sample. This assembly was placed alternately in warm water, an ice bath, and a lead pit at 475° C, and the necessary readings were made to obtain Fig. 7. It should be noted that, had the resistance been plotted for room temperature rather than 0° C, no increase would have been found. These results suggest that there would be a rather large increase in resistance at lower temperatures.

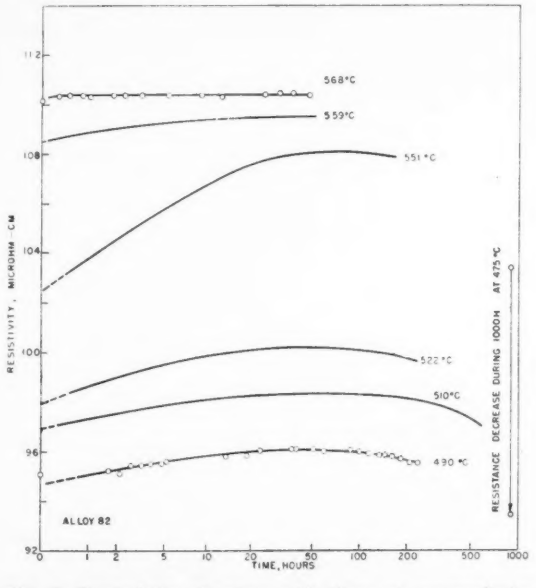

Fig. 8—Resistivity changes with time at successively higher temperature of a 30% Cr–Fe alloy following ageing at 475° C.

It was supposed that the temperature required for complete re-solution of the precipitate could be determined accurately by a series of isothermal ageings at increasing temperatures after the resistance had fallen during precipitation. While this method did not prove to be as satisfactory as continuous heating, it did provide certain information. Typical results are shown in Fig. 8. Since the furnace required about one hour to reach each new temperature the early parts could not be followed accurately. Nevertheless, the results show that the changes are characterized by at least two processes. Initially, the resistance increases due supposedly to changes in composition of the precipitate and matrix. With longer times at the three lower temperatures the resistance starts decreasing eventually, and this is considered a result of additional precipitation. An accurate re-solution temperature is not obtained, but it is apparent that 551° C is roughly the temperature required.

In obtaining the data for Fig. 8, it was apparent that a fairly large resistance change was time dependent, but that most of it could not be followed in that set-up. For this reason, the apparatus used to

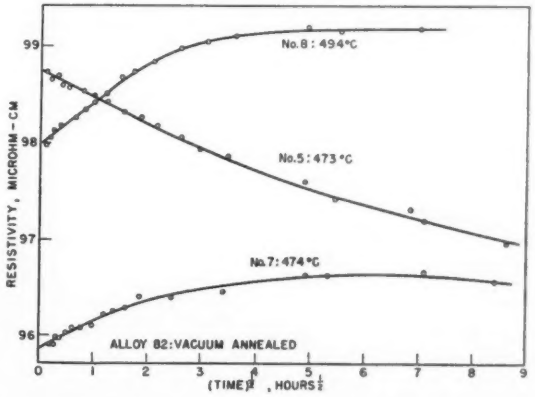

Fig. 9—Time dependence of resistivity of a 30% Cr–Fe alloy after a temperature change of 25° C

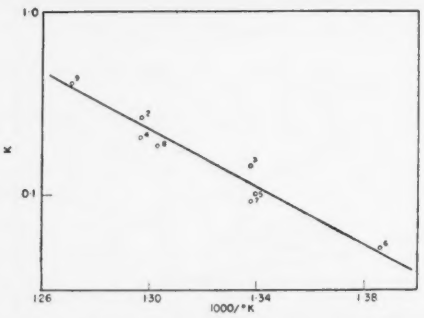

Fig. 10—Log of rate constant for time dependence of resistivity versus reciprocal of absolute temperature

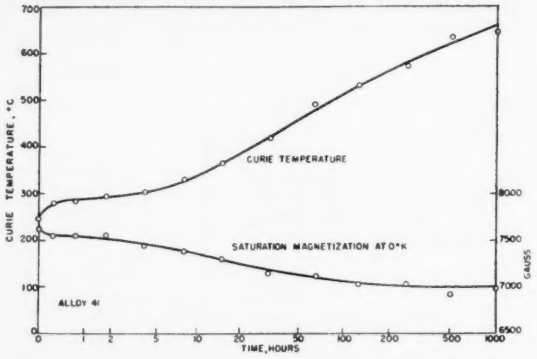

Fig. 12—Curie temperature and saturation magnetization of a 53% Cr–Fe alloy aged at 475° C

obtain rapid temperature changes was used to follow these changes. The sample was aged at 475° C for 70 h and then switched to a lead pot about 20° to 25° higher and the resistance followed. The temperature response was sufficiently rapid that the first reading could be obtained in less than one minute. This switching was continued up and down until about nine steps had been performed. It was possible to represent the initial resistance change as $Kt^{1/2}$ or $Kt^{1/3}$ with approximately the same accuracy. Typical results are plotted in Fig. 9 for three steps. This initial slope K, was corrected for a temperature change of 25° on the basis that its magnitude was proportional to the temperature change. These values are plotted in Fig. 10, log K versus the reciprocal of absolute temperature. The results can be represented adequately by a straight line corresponding to an activation energy of 36,000 cal/mol.

For the magnetic work a sample containing 53% Cr was chosen so that the initial Curie temperature would fall appreciably below 450° C. The results for Alloy 41 are shown in Figs. 11 and 12. In Fig. 11 the magnetization is given as a function of ageing time and temperature for progressive ageing times. The curves are similar at all times to those for pure metals, although the magnetization decreases for this alloy somewhat more rapidly at lower temperatures and less rapidly as the Curie temperature is reached than for pure metals. It is evident that the Curie temperature cannot be directly obtained for times of ageing in excess of 64 h. To obtain the Curie temperature for the longer times and to estimate the saturation magnetization at absolute zero, it was assumed that the data would fit an equation of the form

$$I/I_0 = F(T/\theta),$$

where I is the magnetization at some temperature T, and I_0 is the magnetization at absolute zero. F is some function of the ratio T/θ, where θ is the Curie temperature. By the graphical use of this expression it was possible to obtain reasonably good

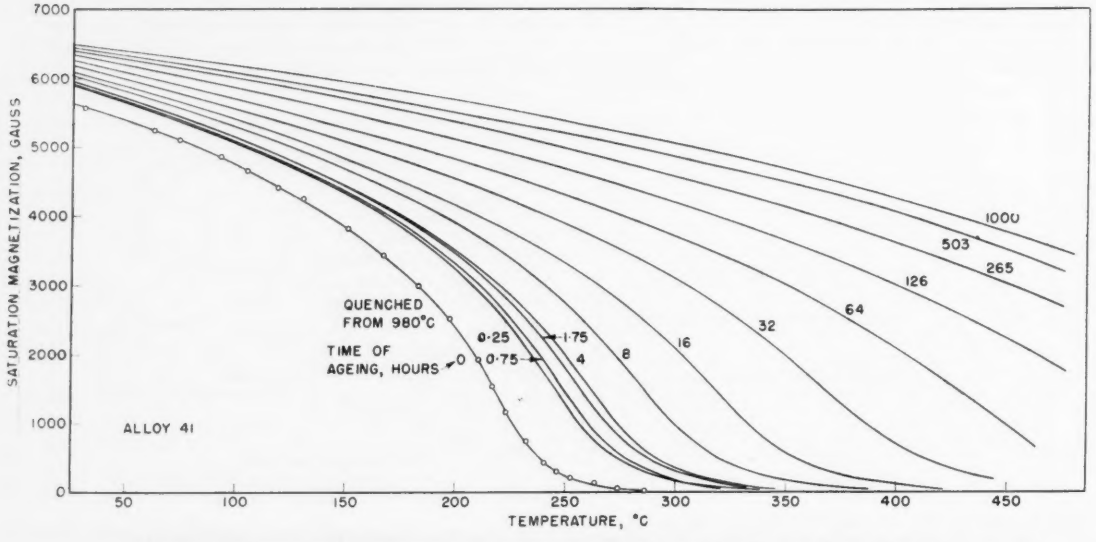

Fig. 11—Magnetization/temperature curves for a 53% Cr–Fe alloy aged at 475° C

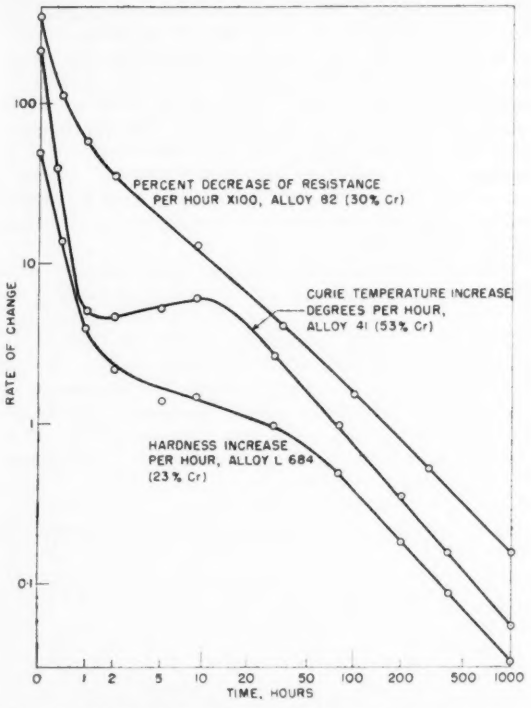
PERCENT DECREASE OF RESISTANCE PER HOUR X100, ALLOY 82 (30% Cr)
CURIE TEMPERATURE INCREASE, DEGREES PER HOUR, ALLOY 41 (53% Cr)
HARDNESS INCREASE PER HOUR, ALLOY L 684 (23% Cr)
RATE OF CHANGE
TIME, HOURS

Fig. 13—Rates of change of electrical resistance, Curie temperature, and hardness of Fe–Cr alloys during 475° C ageing

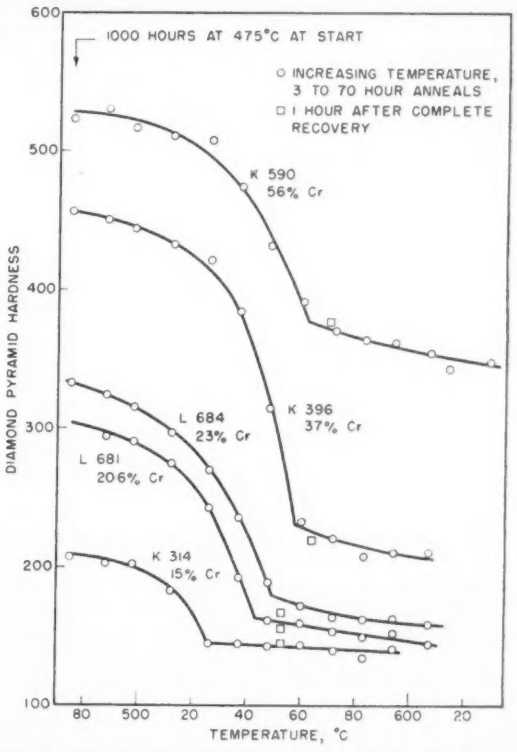
1000 HOURS AT 475°C AT START
INCREASING TEMPERATURE, 3 TO 70 HOUR ANNEALS
1 HOUR AFTER COMPLETE RECOVERY
K 590 56% Cr
K 396 37% Cr
L 684 23% Cr
L 681 206% Cr
K 314 15% Cr
DIAMOND PYRAMID HARDNESS
TEMPERATURE, °C

Fig. 14—Hardness recovery of aged high-purity Fe–Cr alloys annealed at successively higher temperatures

values of Curie temperature and saturation magnetization at absolute zero, although this expression does not hold exactly. These quantities are plotted in Fig. 12 as a function of time. The marked similarity between hardness, resistivity, and Curie temperature should be noted.

While the method of plotting the time scale was convenient for representing the data, neither this nor any other method is capable of showing well the rates of change when they cover such a wide range. For this reason actual rates for hardness, resistivity, and Curie temperature change have been extracted from the graphs already presented and are given in Fig. 13. It is unfortunate that data adequate for the determination of all three rates from a single alloy did not exist. For this reason, it is not known if the second 'break' would coincide for a given alloy. It should be noted that the rates change by a factor in excess of a thousand during the ageing. It is convenient to speak of the ageing as occurring in three stages as defined by the two more-or-less sharp breaks in this figure.

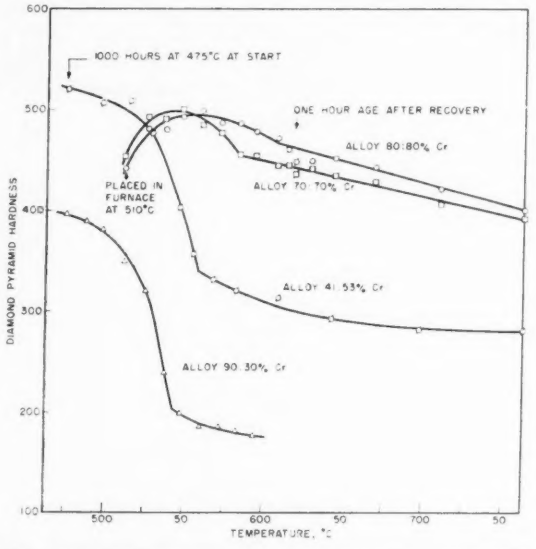

Fig. 15—Hardness recovery of aged Fe–Cr alloys annealed at successively higher temperatures

Effects of Elevation of Temperature

So far, all the results have been obtained from isothermal treatments, and for hardness and resistivity it has been demonstrated that essentially constant values are reached with sufficient holding times. This immediately suggests that following these properties with continuous heating could be used to study the effects of the re-solution of the precipitate. It has been found that step heating is entirely satisfactory for hardness and magnetic measurements, but continuous heating is preferable for resistivity.

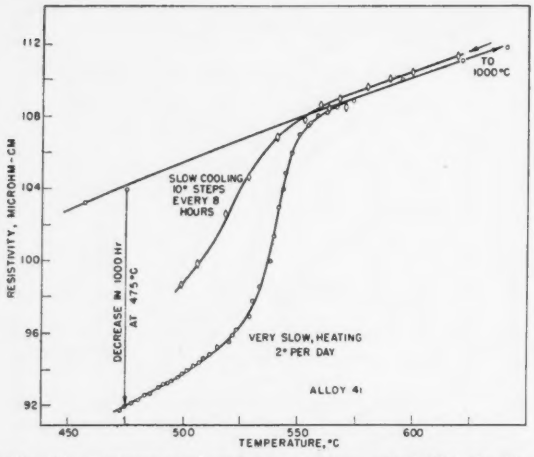

Fig. 16—Recovery of resistance of an aged 53% Cr–Fe alloy during slow heating

The principal results for hardness are shown in Figs. 14 and 15. It will be noted that the series of alloys in Fig. 14 is the same as given in Fig. 2 for isothermal ageing. It has been shown during this work that about three days are sufficient to establish the new hardness after a temperature change for the lower temperatures and less for the higher ones. The results shown here, except for Alloys 70 and 80, are to be considered equilibrium hardnesses. Proof that this is the case for Alloy 90 is given by comparing the hardness on heating with that for isothermal ageing, Fig. 5. Within the accuracy of the measurements they are the same. Some evidence was found which suggested that the hardness would follow the same curve on cooling if this were done slowly enough. It has been convenient to show a break in these curves, although the data do not establish that the change is so abrupt. That the decrease above the break is real, and associated with a change in the solid solution which occurs rapidly, is shown by the hardnesses obtained by re-ageing just above the break for 1 h samples quenched from high temperatures. Except for possibly Alloy 80, all those so aged gave increases which placed the points very near the curves obtained from step heating.

It was shown in Fig. 8 that step heating was relatively unsatisfactory for resistance; so heating at 2° C per day was tried. The results for most of the alloys have been tabulated already in Table II. Figure 16 shows part of the data graphically. It was established that the region where the resistance is increasing towards the un-aged value is essentially an equilibrium process. The fact that on cooling at a much faster rate the same shape curve is obtained to some point past the break is partial evidence. Here, the resistance values do not break sharply, and no accurate value can be obtained for complete recovery. It is supposed that the presence of impurities was partly responsible for this in Alloy 41 and also for many of the rest. Moreover, for those alloys containing around 30% Cr the effect was considerably worse and only ranges for recovery could be established. This is no doubt partly connected with the loss of ferromagnetism simultaneous with re-solution. Figure 17 gives a better overall picture of the entire process. This was a purer alloy and the break as shown agrees very well with those for the hardness of the purer series.

Magnetic measurements were made with step heating analogous to the hardness and the results are

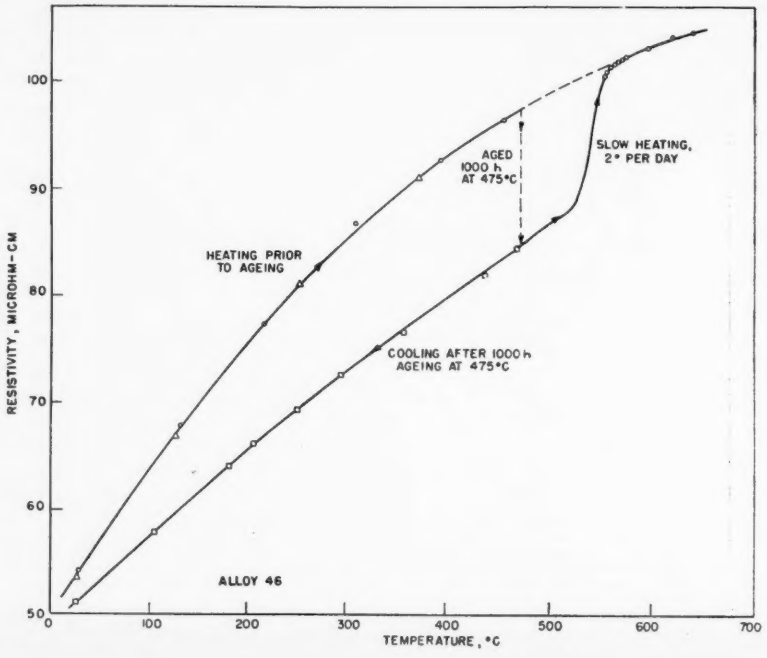

Fig. 17—Temperature/resistivity curves for a 46% Cr–Fe alloy before and after ageing

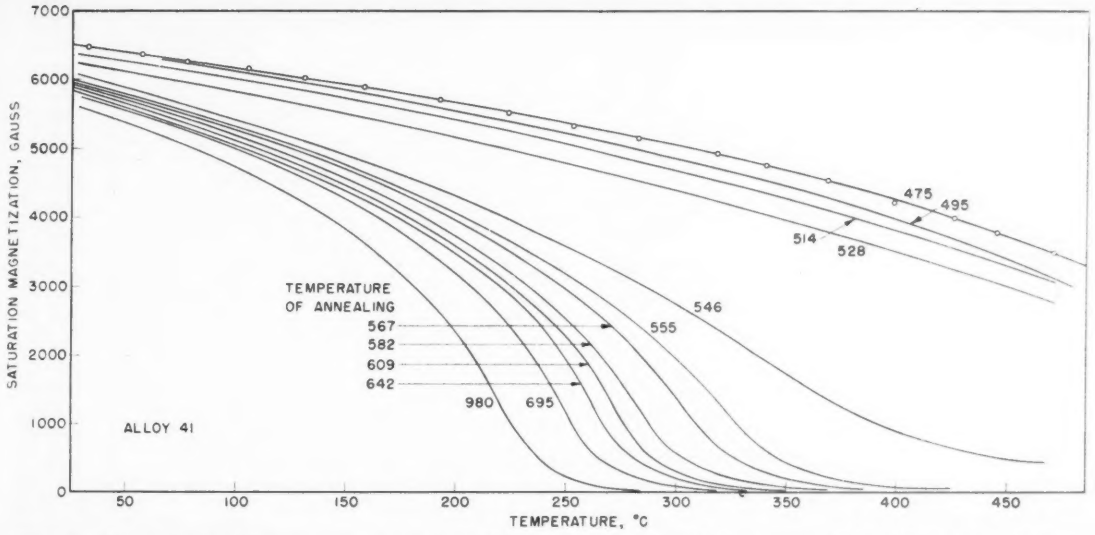

Fig. 18—Magnetization/temperature curves for a 53% Cr–Fe alloy annealed at successively higher temperatures

plotted in Figs. 18 and 19. The behaviour almost exactly parallels that for hardness. The tail-off above the break of the Curie temperature versus the temperature of holding is more pronounced than for the hardness; and it was found that a higher quenching rate from temperatures above 700° C could reduce the Curie temperature by at least 25° more.

Alloy 80 was heated at successively higher temperatures and the force required to separate the sample from a given magnet was measured and is plotted in Fig. 20. It is apparent that these data do not accurately give the temperature required for re-solution, although it is useful information in the absence of more extensive data on this alloy.

Sigma Phase Formation

It is well known that sigma will form in Fe–Cr alloys in the compositional and temperature range of interest in this study. It was thus necessary to make certain that none of the changes which were found could have been effects of σ-formation. As it turned out, the only alloys which showed sigma in any case were the resistivity samples which, for the first run, had been heavily cold reduced. In this case, no sigma could be found after ageing up to 510° C, but most of the samples contained appreciable sigma on reaching 550° C. The only graphical data reported here where sigma was formed are those for Alloy 82 in Fig. 8. This sample had a few per cent. of sigma on reaching 550° C. However, it could not be determined for this or any other case exactly what effect sigma had on resistivity and so the effect must have been slight. Undoubtedly, the reason that sigma was not formed in subsequent runs is that the material had been recrystallized and the holding times were somewhat shorter.

The question naturally arises as to whether sigma will form in very long times at the lower temperatures of ageing. If it will not, the mixture of the Fe-rich matrix and the Cr-rich precipitate is more stable and a eutectoid temperature must exist below which sigma is unstable. Unequivocal proof of the existence

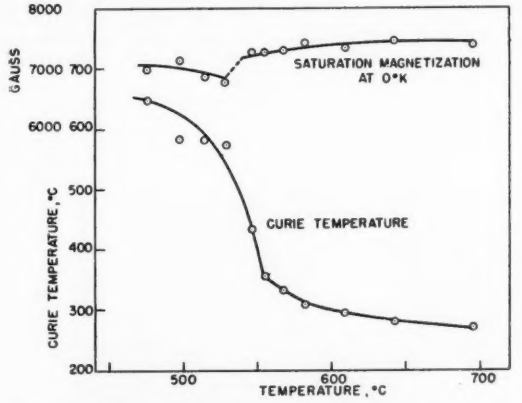

Fig. 19—Curie temperature and saturation magnetization of a 53% Cr–Fe alloy annealed at successively higher temperatures

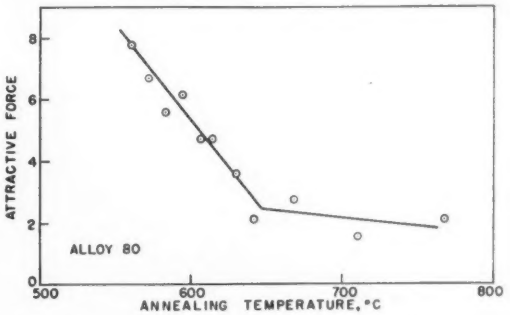

Fig. 20—Magnetic behaviour of a 80% Cr–Fe alloy with successively higher-temperature anneals

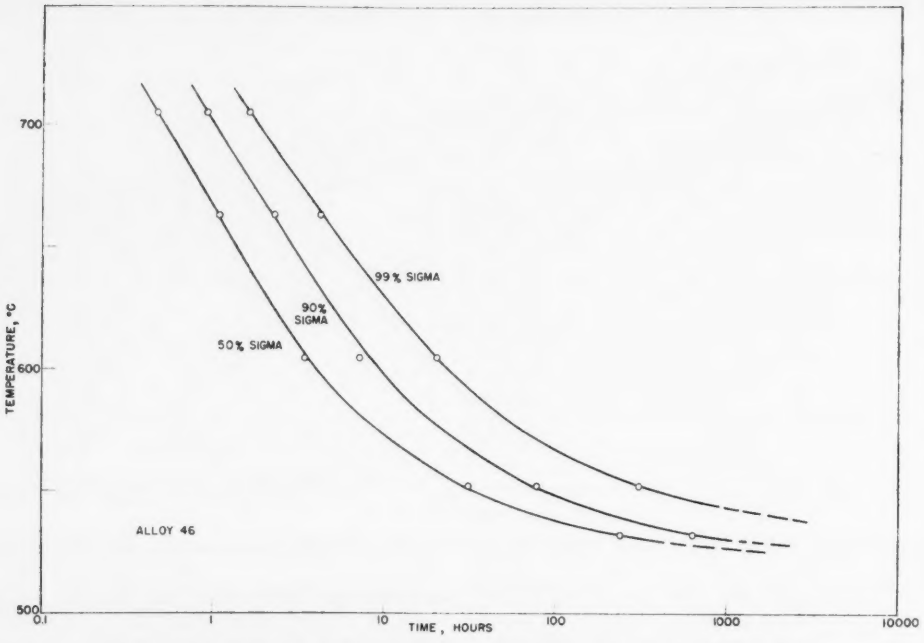

Fig. 21—Kinetics of sigma formation in filings of a 46% Cr–Fe alloy

of such a eutectoid would consist of evidence that sigma decomposes into the mixture of body-centred-cubic phases. Even if this eutectoid reaction were proved to exist by the above method, it would still remain to determine its temperature. An alternate method is to determine the kinetics curves for the formation of sigma at successively lower temperatures, a eutectoid temperature being demonstrated by the existence of increasing reaction times without bounds. For such a determination, filings of Alloy 46 were sealed in Pyrex tubing under vacuum and aged for successive time intervals. The formation of sigma could be followed reasonably well by measuring the attractive force between the filings and a permanent magnet. The results are plotted in Fig. 21. It is immediately evident that the reaction times become abnormally long at lower temperatures just as predicted. The best estimate for the eutectoid temperature is 520° C. It might be noted that the relative times for reaction to go from 90% to 99% becomes progressively longer with falling temperatures. This is explained by the existence of small regions falling outside the narrowing single-phase field as a result of normal freezing behaviour. A sample containing 99% σ and 1% ferrite was held at 490° C for 190 h with no apparent change.

In trying to fit together these data concerning the shape and position of the miscibility gap, the eutectoid temperature, and the sigma field according to Cook and Jones,[16] there was considerable uncertainty about the higher-Cr regions. It was planned to establish certain phase boundaries by reacting Alloy *K*590 (50% Cr) to sigma and the phase in equilibrium with it and then analysing this phase. It turned out that the rates of formation of sigma were very appreciably less than for Alloy 46 and equilibrium could not be approached in several hundreds of hours. This experiment produced only two pieces of useful information. Sigma was found after ageing at 530° C and there was a suggestion of a change of rate between 583° and 591° C. This possibility of a change in rate is the most direct evidence for a higher eutectoid temperature.

The work of Fisher *et al.*[1] has shown the particles

Fig. 22—Rotation pattern of single crystal of alloy 79 (30% Cr) aged 1·75 h at 475° C. Cr radiation, 0·17 min/degree exposure

formed during precipitation to be too small to be seen by a light microscope. They were able to clearly show the particles by an electron microscope only by special techniques. The present work required considerable microstructural work for control and σ detection, but no effects of ageing were apparent using electrolytic polishing. Some standard electron microscopy was done in this work, but no particles were clearly seen.

X-ray Diffraction

Several reports have been made of the change in nature of the diffraction patterns from aged Fe–Cr alloys. However, this work has shown that these effects must have been due to improper techniques since it has been impossible to find any effect whatsoever using great care. The one genuine effect which has been reported was due to the precipitation of a nitride[8] and does not appear to be directly associated with ageing. In this work use was made of Debye–Scherrer and single crystal techniques including Laue, rotating, and oscillating crystals. The most intensive series was made using a single crystal rotating or oscillating about a [110] axis through the positions for characteristic reflections.

Three more or less representative patterns are shown in Figs. 22 and 24. Of these, Fig. 22 represents a rotation pattern after ageing 1·75 h at 475° C using an exposure of 0·17 min/degree (the splitting resulted from the axis being slightly off from the [110] direction). Figure 23 represents the pattern after the sample had been given the following treatment: 1000 h at 475° C, 190 h at 510° C, 48 h at 500° C, 100 h at 450° C, and 150 h at 425° C. Although detail has been lost in reproduction, it is noticed that the only extra feature is the diffuse tail on the high-angle side of the spots. The spots themselves appear unchanged. This diffuse effect apparently is due to surface relaxation occurring during the ageing

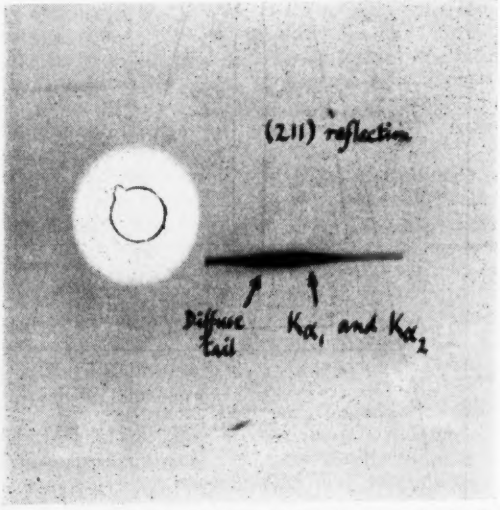

Fig. 23—Oscillation pattern of single crystal of alloy 79 (30% Cr) after prolonged ageing showing diffuse effect. Cr-radiation (211) reflection, 8 min/degree exposure

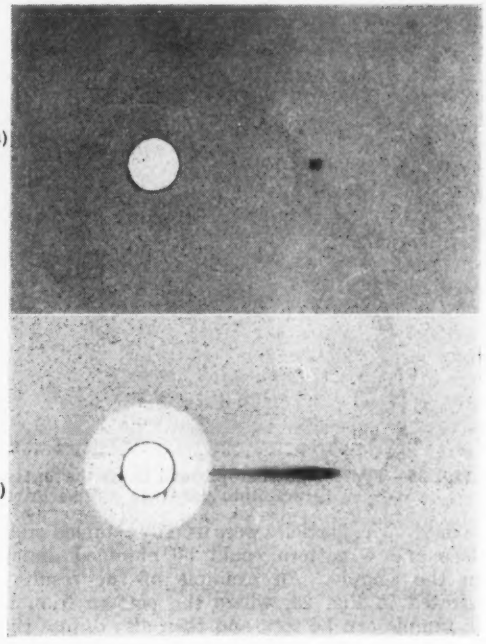

Fig. 24—Oscillation patterns of single crystal of alloy 79 (30% Cr) after prolonged ageing with repolish (Cr-radiation, (211) reflection)
(*a*) 0·27 min/degree (*b*) 16 min/degree

treatment because if the surface is again electropolished, this effect disappears as shown in Fig. 24. The thickness of this layer in which the iron-rich matrix has relaxed to a more or less strain-free state is estimated to be 1000–5000 Å thick.

Figure 24 gives two patterns of the sample after electropolishing and represents two extremes of exposure times. The degree of resolution is clearly indicated in Fig. 24*a*. Except for the surface effect discussed above, all patterns obtained were indistinguishable under visual examination when due consideration was given to the exposure times. Broadening and other diffuse effects must be very slight.

It might be noted on these patterns that there is a weak line at lower angles than the characteristic spots. This is a satellite line and has been found on patterns of other material using chromium radiation and definitely is not associated with this ageing.

By obtaining rotation patterns for the single crystal, it was possible to make accurate measurements of the lattice parameter. The average deviation was less than 0·01%, and so it is concluded that no change as great as 0·0003 Å took place. This corresponds roughly to the uncertainty of room temperature. The measured value of 2·8675 Å checks very well with the values of Preston[17] for a 30% alloy.

A simplified technique based upon the work of Fischer *et al.* for the extraction of the precipitate particles was used.

Here, a small region of the sample was exposed to a mixture of picric and hydrochloric acids in alcohol

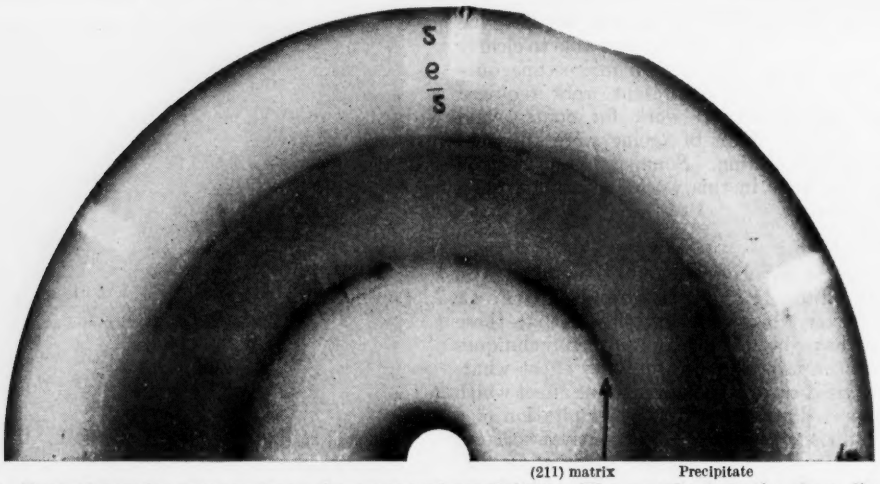

Fig. 25—Typical powder pattern from the extracted precipitate. The matrix gave the sharp lines, the precipitate gave the diffuse lines, of which the (211) is most prominent

for a day. The particles were usually retained on the surface and a pattern could be obtained directly from the sample. An example of the results is illustrated in Fig. 25, where the pattern from the bulk sample can be seen and then also diffuse rings just outside which are from the freed precipitate. The effect is particularly apparent on the innermost rings corresponding to the (211) reflection. The results for Alloy 90 in the hot-rolled condition are given in the following table:

Temperature of Ageing, °C	Time, h	Line Half Width of (211) Reflection,°	Particle Size, Size, Å
475	1000	none found	...
495	800	5	85
515	600	3	140
530	slow heating	2	200

The particle size has been estimated by using Scherrer's equation[18] and the results are probably accurate to better than a factor of two. The same technique was tried on the hot-rolled alloys from the Electro Metallurgical Company, but no results were obtained because the particles washed off the surface. Unaged samples naturally gave no residue. Accurate values of the lattice parameter were not obtained, although it appeared to be 0·0007 Å greater than the matrix. This corresponds at face value to a Cr content of 80%, according to Preston's data.[17]

DISCUSSION OF RESULTS

In the preceding sections the experimental results associated with the ageing of alloys of iron and chromium have been presented. But for a few exceptions, these results are in agreement with previous investigators. It was found that pure alloy did age, but no explanation for this difference from results of Becket[3] and Lena and Hawkes[8] was found. Also no X-ray diffraction effects were found in contrast to results of previous investigators.[4, 7, 8] This work has also added a number of new details concerning this ageing reaction.

This ageing, or 'embrittlement,' of Fe–Cr alloys is found to be the result of the precipitation of small, coherent particles rich in chromium as a result of the existence of a miscibility gap in the system. This idea is completely different from the proposal that the ageing resulted from the precipitation of some minor phase[12, 19] (oxide, carbide, nitride, phosphide, or sulphide), or that it was ordering.[6, 10, 20, 21] Also, it was not possible to confirm Lena and Hawkes' idea[8] that nitrogen was necessary in high-purity materials.

It is considered incorrect and unnecessary to term this precipitate a transition structure connected with the formation of sigma as proposed in the most common theory of ageing.[1, 2, 8, 22, 23] On the basis of

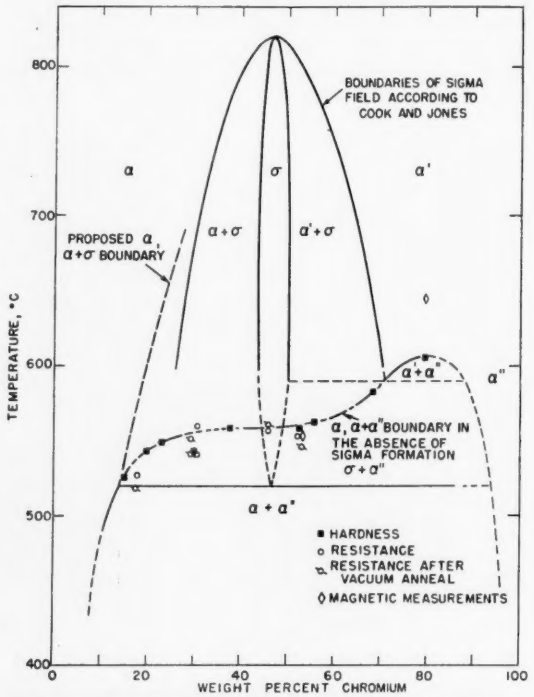

Fig. 26—Partial phase diagram of the Fe–Cr system

crystal structure, thermodynamics, and composition, it seems completely unreasonable to associate sigma with this Cr-rich phase.

Without exception, these results on ageing can be explained on the basis of a miscibility gap in the Fe–Cr system, as shown in Fig. 26. The sigma fields, according to Cook and Jones,[16] and the previously-mentioned eutectoid reactions, have been included. The miscibility gap, in the absence of sigma, has been drawn in according to the results of high-purity alloys, principally the hardness results in Figs. 14 and 15, although satisfactory agreement between hardness, resistivity, and Curie temperature has been shown. The presence of 1% Si and Mn together lowers the re-solution temperature about 10° C and lowers the bottom eutectoid temperature somewhat more since sigma is occasionally found in commercial alloys at as low as 480° C.[1, 24] No significant difference was found between alloys with low (0·002%) and high (0·38%) nitrogen contents.

In order that the lower eutectoid temperature, the miscibility gap, and the $\alpha/\alpha + \sigma$ boundaries agree in the left part of the diagram, it is necessary to reposition one line. It was believed that the gap and the eutectoid temperature were the more accurate, and hence a new position of the $\alpha/\alpha + \sigma$ boundary has been suggested. In reviewing the work of Cook and Jones,[16] it is not too surprising that their boundary could be off the required amount since the establishment of such a boundary by their method is very difficult.

Difficulties are also encountered in the high-Cr region, and the unsuccessful attempts to get additional data have been presented. It is obvious that the $\alpha + \sigma/\alpha$ boundary on the chromium side must be moved markedly to the right if it is to intersect the gap to give a single eutectoid temperature of 520° C. Reference to Cook and Jones' work suggests that this boundary may have been more accurately determined, so that an alternate course has been taken. It is supposed that a second eutectoid temperature exists at 590° C, as shown. Besides this indirect evidence, the kinetics of σ-formation in the 56% alloy also gives some hint of its existence. For the sake of completeness, it is regrettable that this high-chromium side could not be established with greater certainty.

The complete miscibility gap, in the absence of sigma, is seen to have a concave upward portion which has not been previously found for a miscibility gap. The results are rather conclusive in showing that this dip is real and is not associated with actual σ-formation. If it is supposed that this dip is associated with the potential to form sigma, then it must be concluded that the forces responsible for sigma can also modify the energy of the solid solution prior to any change in crystal structure.

This incompatibility between iron and chromium is somewhat surprising in that the size difference is so slight and normally both are considered to have the same valence in the metallic state. Assuming this, one then supposes that chemical energy must be responsible. In this case, however, it seems reasonable for magnetic effects to be fairly important. Indirect evidence includes the fairly small energy release on ageing,[10] the marked changes in Curie temperature on precipitation and clustering, the ferromagnetic state of iron and the anti-ferromagnetic state of chromium at room temperature. In the absence of some definite model it is not possible to know if magnetic effects could be responsible for the odd shape of the miscibility gap.

The temperature dependence of the hardness and Curie temperature and, to a much lesser degree, the resistivity which have been found above the miscibility gap (Figs. 14–17 and 19) are considered to result from increasing clustering with decreasing temperature. The high initial rates of precipitation are essentially in agreement with the idea that the nuclei are present at the start, a condition consistent with marked clustering. The notable case where short-range ordering has been found above a miscibility gap comes from the work of Flinn *et al.*[25] on the nickel–gold system where the large size difference was shown to be responsible. The present system could not be expected to behave similarly. It might be noted that it is essentially this clustering (accompanied possibly by minor precipitation) which caused the formerly unexplained changes in Curie temperature in this system as found by Adcock.[24]

Examination of the figures showing the changes in hardness, electrical resistance, and magnetic properties during isothermal ageing suggest that the process is rather simple and straightforward. These curves can be conveniently divided into three more or less distinct parts; first, a very rapid, decreasing rate, second, a more or less constant rate, and finally, a decreasing rate. Primary graphs show these stages fairly well, but the rate curve, Fig. 13, shows them best. The magnitude of the change of rate should be noted.

It has been pointed out that clustering is considered to exist in the alloys even prior to quenching, so that nucleation need not be considered as rate controlling, even for very short times. For this reason, it is not too surprising that the ageing process should start out at a high or maximum rate. However, it is somewhat surprising that the rate decreases by a factor of ten within the first hour (at 475° C) prior to a realization of more than 10% reaction. Two possible explanations of this have been considered. It might be supposed that some degree of clustering, distinct from precipitation, occurs in very short times in a fashion similar to that found above the miscibility gap. It seems more reasonable, however, that the excess vacancies which were quenched-in by rapid cooling increase the diffusion rate and thus give a high initial rate. It would thus be supposed that the excess number of vacancies reaches approximately equilibrium concentration in 1 h at 475° C. This picture is in qualitative agreement with the effects of quenching temperature, as shown in Fig. 4, in that a higher quenching temperature gave a higher initial rate. It is realized, however, that higher quenching temperatures would also change the degree of clustering so that a detailed analysis is not easy. On the basis that this first stage is due to excess vacancies, the apparent activation energy for the completion of this step of 55,000 cal-mol would seem too high. This should not be taken too seriously

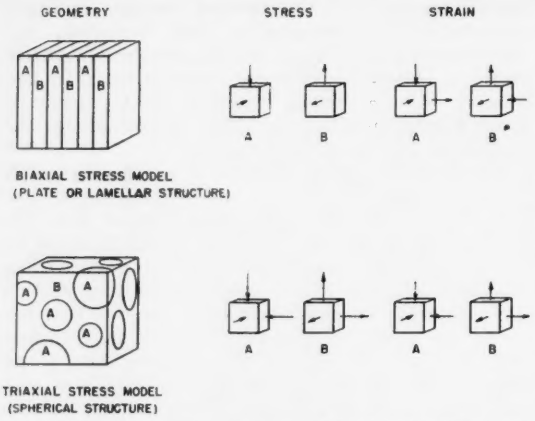

Fig. 27—Stress and strain models for biaxial and triaxial cases

until the process can be examined in greater detail.

Qualitatively, the later stages of ageing apparently occur by simple depletion of the solid solution. It is supposed that the change from the second stage to the third results from the interfering of depleted regions of adjacent particles, but this has by no means been proven. The marked parallel between hardness, resistivity, and Curie temperature is noteworthy in that this type of behaviour is uncommon in ageing reactions. This is due in part to the slow growth of the precipitate after precipitation, and the fact that it never loses coherency.

While overageing is very common in precipitation systems, it is not difficult to explain its absence in this system. The particle growth required for overageing can be expected to occur very slowly on the basis of considerations of driving force and diffusion. When the particles have reached a size of 100 Å, the driving force, interfacial energy, will be no more than 8% of the initial driving force. Since the distances for diffusion are now about twice that during precipitation, the rate of particle growth would not exceed 2% of the rate of precipitation. Such a slow process would not be detected by the experimental methods used.

Some particle growth was found in the particle size measurements, but this occurred when the temperature was increased, so that diffusion was much faster. It might be noted that the hardness decrease resulting from increasing temperatures is indicative of decreasing amounts of precipitate and lessened strains rather than particle growth. It was not possible to show any dependence of hardness on particle size within the scope of this work. Probably, the most significant reason why these particles do not lose coherency is that for such small particles the necessary dislocations would represent more energy than they could release.

The application of the diffusion data of Buffington *et al.*[27] along with the methods of Zener,[28] predicts particle sizes consistent with those observed.

It has become customary, as a result of theoretical work, to associate the initial shape of a particle with the degree of strain, as noted by Hardy and Heal.[29] On this basis, it is not surprising that particles in the Fe–Cr system start out spherical since the strain is rather small.[1] However, the problem does not seem to be well elucidated for there are other systems similar to this system yet the earliest detectable stages consist of coherent plates of about 20–40 Å thickness. Two examples are the Cu–Ni–Fe and the Cu–Ni–Co systems which have been extensively investigated.[30, 31, 32, 33] In the authors' opinion, these systems are rather well understood from a structural standpoint and the state of coherency strains as found by X-ray diffraction are represented in the top of Fig. 27 for a single set of (100) planes. Since the two phases are coherent on cube planes, one observes experimentally three sets of orientations of a double tetragonal structure, the '*c*' axis being parallel to the original cube poles. This duplex structure has *c*/*a* ratios just less than, and just greater than, unity.

On the basis of the absence of X-ray diffraction effects for the aged Fe–Cr alloys, it must be assumed that both the matrix and precipitate are essentially isotropically strained to a common lattice parameter, that of the undecomposed alloys. The strain state which is believed to exist is illustrated at the bottom of Fig. 27. It is not possible to predict what the uniformity of strains should be for, say, a random collection of coherent spheres, since the only calculations have been based on a single particle. The lack of X-ray diffraction effects is offered as evidence that the proposed isotropic strain state is very nearly correct. This is in agreement with the theoretical work of Eshelby[37] for a collection of strain centres.

A simple calculation suggests that the strain energies are too small in this system to be very important in determining the structure or in causing a loss of coherency. If Preston's data[17] are used for the lattice parameter and an equi-atomic alloy were completely aged at 475° C, the following values are obtained. If the structure were plate-like, as in Cu–Ni–Fe, the strain energy at room temperature would correspond to 2·2 cal/mol, while an isotropic strain state would correspond to 5·6 cal/mol, where both results are based on the bulk elastic constants of iron. While the plate structure has significantly lower energy, in neither case is the magnitude considered important. If one estimates the lattice parameters at 475° C from available data,[34, 35] the strains can be expected to decrease by about a half, so that the above energy values would decrease by a factor of four, even if the modulus had not decreased. It seems likely that the importance of unequal expansion rates in such calculations has been overlooked in the past.

It seems unreasonable to explain the hardening during precipitation of these materials in terms of the usual dislocation model (see Hart[36] for a review of this subject), since it seems unreasonable to expect the particles to be able to withstand great shearing forces in that they are continuous with the matrix and the slip planes are undistorted as judged from the X-ray diffraction results. As an alternate explanation, it is proposed that the particles interact with the hydrostatic stress components of the edge dislocations since both the matrix and particles are considered to be hydrostatically stressed. An illus-

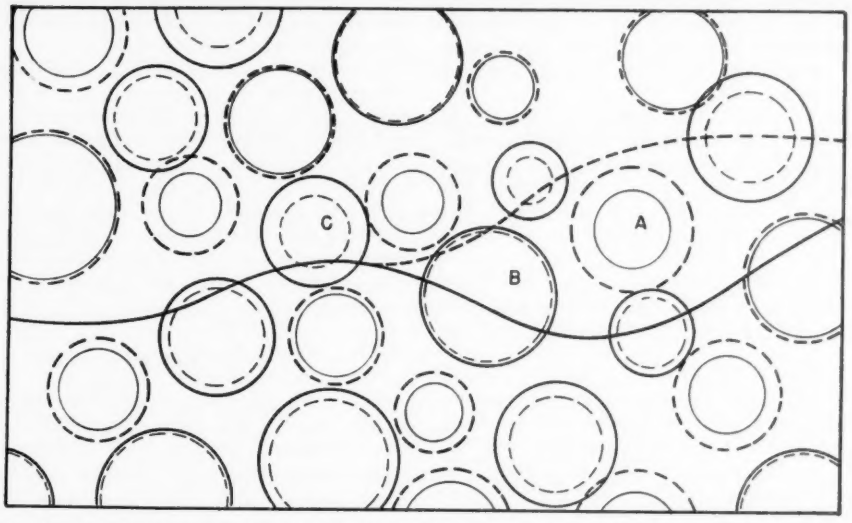

Fig. 28—Model of interaction of edge dislocation and hydrostatically stressed particles

tration of how such a model would cause hardening is given in Fig. 28. Here, the particles of chromium are considered to be spherical and in compression, while the iron-rich matrix is in tension and the extra plane of atoms of the dislocation is considered to extend beneath the plane of cut. Particle '*C*' lies almost wholly in the tension region of the dislocation and thus attracts it strongly. Particle '*B*' lies roughly centred on the slip plane and offers little interaction, while '*A*' repulses the dislocation strongly since it lies below the plane. At some earlier time it is supposed that the dislocation was in the dotted position until a stress was applied which forced the dislocation to roughly the centre of particle '*A*', where it then snapped into the position shown here and dissipated the supplied energy as lattice vibrations. One must then supply a greater amount of energy to slip aged material.

A detailed mathematical analysis of this model has shown it to be capable of predicting roughly the observed hardening and the apparent lack of dependence on particle size.

There are too few data on the resistivity of the Fe–Cr system, such that all the effects which have been found can be explained in detail. It is not known why the resistivity decrease at elevated temperatures is so much greater than at room temperature. The very slight rise in resistivity at 0° C during ageing at 475° C may have been due to particle size, but for longer times and higher temperatures the resistivity seemed independent of particle size. The time-dependent change of resistivity for aged samples in the ageing range is considered to result simply from diffusion as dictated by the phase diagram. The fact that it starts off proportional to the square root of time and appears to end as an exponential decay gives some credence to this idea. The apparent activation energy for this process of 36,000 cal/mol would seem too small, but the process should be examined in greater detail before this is concluded.

SUMMARY AND CONCLUSIONS

The principal conclusions which have been reached as a result of this work are:

(1) The so-called "475° C embrittlement of ferritic stainless steels" is actually an ageing or precipitation hardening phenomenon. This precipitation is a result of the existence of a miscibility gap in the Fe–Cr system at these temperatures. The precipitate may be considered to be body-centred-cubic chromium which contains small amounts of iron.

(2) This miscibility gap is connected by a eutectoid reaction at 520° C to the region where σ-phase is stable, and also, there seems to be a second eutectoid temperature at about 590° C. For the most part, the miscibility gap was studied in the absence of σ-phase, and would appear to have two inflexion points and to be skewed toward the chromium side.

(3) Chemical, or magnetic energies, or both, are considered to be responsible for this miscibility gap to the exclusion of either strain energy or valency effects.

(4) The presence of short-range clustering above the miscibility gap is demonstrated by the change in hardness and Curie temperature with temperature. This clustering is also considered to be partly responsible for rapid initial rates of precipitation in that the nuclei can be considered to be present at the start.

(5) The very high initial rate of ageing is considered to result from the presence of excess vacancies and is dependent on quenching temperature.

(6) There were no apparent differences in rate of precipitation between pure alloys and those containing the normal impurities. In particular, changing the nitrogen content from 0·0015% to 0·2% in an alloy produced no noticeable effect.

(7) The magnitude of this ageing decreased in high-chromium and low-chromium alloys. The type of behaviour was very similar for alloys between 20 and 60% chromium, but the kinetics appear to

change somewhat with higher chromium contents.

(8) No difference was apparent in the ageing behaviour of cold-rolled, hot-rolled, recrystallized, or large-grain material.

(9) On the basis of X-ray diffraction work, the particles appear to be larger the higher the temperature of precipitation. Particles formed at lower temperatures will grow at higher temperatures, but isothermal growth may be too slow to detect. The range of particle sizes which are expected are 300 Å and down.

(10) The hardness is dependent upon amount and composition of the precipitate, but it was not possible to show any dependence upon particle size from these data.

(11) The particles do not lose coherency at any time, and this is considered to be a result of the small strain energy and the small particle sizes. Even with very slow heating rates, the particles apparently go back into solution without losing coherency. On the basis of the absence of X-ray diffraction effects, it is concluded that both the matrix and precipitate are under essentially isotropic stresses and are strained to a common lattice parameter, that of the unaged material.

(12) It seems unreasonable that such particles could withstand substantial shears, and so it is suggested that hardening may arise from the interaction of the particles and matrix with the hydrostatic stresses around the dislocation.

(13) The presence of the normal amounts of silicon and manganese cause the resolution of the precipitate about 10–15° C below the temperature required for high-purity alloys of the same chromium content. Also, the presence of 5% Si will prevent the ageing of a 25% Cr alloy at 480° C.

(14) On the basis of this work, it would seem that the only practical method of eliminating this ageing commercially is by the investigation of useful ternary alloy additions which would lower the top of this miscibility gap.

Acknowledgments

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The Use of Paraffin Wax as a Model Material to Simulate the Plastic Deformation of Metals

ANDREW CARNEGIE RESEARCH REPORT

PART I—A PRELIMINARY INVESTIGATION INTO THE MECHANICAL PROPERTIES OF PARAFFIN WAX

By C. Bodsworth, M.Met., J. Halling, B.Sc.(Eng.) and J. W. Barton, B.Eng.

SYNOPSIS

The paper describes an investigation of the mechanical properties of paraffin wax with a view to its usefulness as a model material for simulating deformation processes.

Results are given illustrating the dependence of the stress/strain behaviour of the material on the strain rate and the temperature. Derivation of the basic stress/strain curves indicates some work hardening of paraffin wax at large plastic strains, the degree of work hardening depending on the temperature. Possible applications of the material are illustrated by the results from extrusion tests which show good agreement with those obtained during extrusion tests of lead. A structure has been revealed by etching of which the form is shown at points in the extrusion process. 1265

MODELS have been extensively employed to simulate the strain conditions during the plastic working of metals. A number of papers[1, 2, 3] have been published describing the use of Plasticine as the model material for investigation of the processes of extrusion, forging etc. where the properties of this material closely conform to the conditions of hot working. Indeed the approximation of this material to the plastic–rigid ideal has enabled several theoretical slip-line fields to be checked experimentally.

This investigation was undertaken in an endeavour to find an alternative model material having greater potentialities than Plasticine in the study of metal deformation. Paraffin wax suggested itself as a possibility since it had already been used in two previous instances[4, 5] as a model material for the study of deformation. Since no details of its mechanical properties appeared to be available, the study of these properties was considered to be the logical commencement for this work.

Several grades of paraffin wax, having different melting points, are available and in this instance 'Scotch wax,' having a melting point in the range 120–125° F, was used. One obvious advantage of paraffin wax over Plasticine is that, whereas the latter is an amorphous material containing small embedded mineral particles, the former has a crystalline structure and is therefore more comparable with the metallic state. Furthermore, a crypto-crystalline wax is now available and hence, by suitable control of the rate of solidification, the effects of grain size over a wide range should be amenable to study.

COMPRESSION TESTS

Specimens cast in the form of a cylinder and machined to a size of 3 in. dia. and 3 in. height were compressed between smooth steel platens in a standard Avery testing machine. Changes in length were determined from a dial gauge (0–1 in. range graduated in 1/1000 in. per division) which was rigidly clamped to the frame of the machine with its anvil resting on the lower (moving) platen. A few preliminary tests showed that the stress/strain relationship depended markedly on both the temperature and the strain rate of the test. Accordingly tests were carried out at a constant strain rate of 0·004 per min and at a temperature in the range 0–35° C.

EFFECTS OF TEMPERATURE

Over the period in which these tests were performed the day-to-day variations in room temperature enabled the tests in the range 15–23° C to be carried out in air. For the tests outside this temperature range the thermostatically controlled water bath shown diagrammatically in Fig. 1 was used. Temperatures below 15° C were achieved by the addition of quantities of ice and salt to the water bath. This bath could be mounted on the testing machine, the load being applied by the vertical loading column *A*. Sheets of asbestos fibre (*B*) were placed between the smooth steel platens in contact with the ends of the specimen and the loading system. This reduced heat losses from the system and in particular ensured that the temperature of the end faces of the specimen was substantially the same as that of the bulk material.

The attainment of a uniform temperature throughout the test specimen was ensured by using the identical reference specimen *C* for each test. This had thermometers inserted at various points across the diameter and no test was carried out until they gave identical readings to within $\pm$ 1/10° C.

It is apparent that the validity of the results would be affected if the water in the bath reacted with the specimen. The interfacial energy between water and paraffin wax is given as 50 ergs/cm^2, and the contact angle as 110°. Although these values may be expected to vary with the grade of wax and the temperature, it was inferred that no reaction occurred. Examination of the specimen surface after the tests showed no visible surface action.

The testing machine was set to give a full scale deflection of 3 tons, thus enabling loading increments of 0·01 ton to be used. For the size of specimen used in these tests this loading increment disclosed slight variations in the stress/strain relationships.

RESULTS

For the tests at the higher temperatures considerable plastic deformation was observed, and a typical stress/strain curve for such a test is shown in Fig. 2. The initial curved portion *AB* is attributable to the

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Mr. Bodsworth is a lecturer in the Department of Metallurgy of the University of Liverpool, where Mr. Barton is a Research student. Mr. Halling is a lecturer in the Department of Mechanical Engineering.

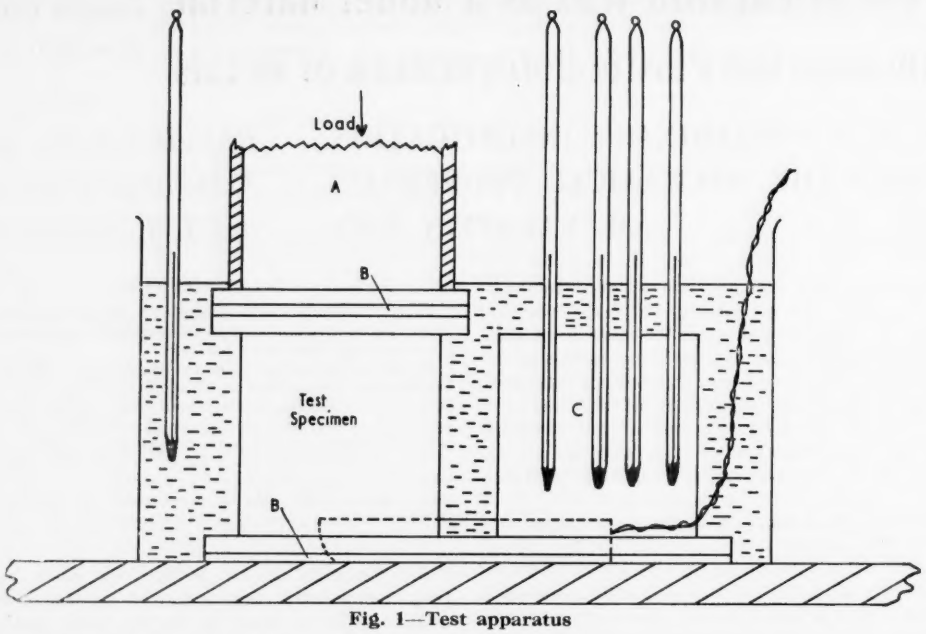


Fig. 1—Test apparatus

deformation of the surface irregularities on the end faces of the specimen and probable slight non-parallelism of these end faces. These irregularities are caused by the machining operation and the non-parallelism is due to difficulty in rigidly locating the specimen in the lathe chuck during machining. The portion of the curve *BC* is substantially linear and over this region the material behaved elastically, as was indicated by complete recovery being observed when the load was removed.

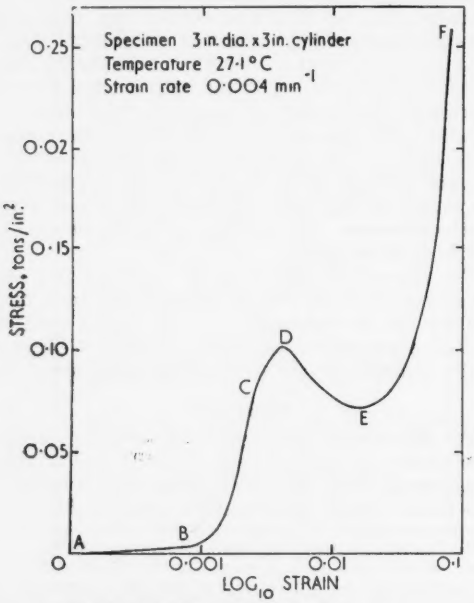


Fig. 2—Typical stress/strain curve

At *C* the curve deviates from linearity and this point was taken to be the limit of proportionality. Thereafter the curve attains a sharply defined upper yield point *D* followed by a fall, initially rapid, but then decreasing to the point *E*. The subsequent rise *EF* is due to the barrelling of the specimen as plastic deformation proceeds. The barrelling observed in some instances was not symmetrical, probably owing to slight differences in the frictional conditions at the two ends of the specimen and associated with a slight thermal gradient throughout the depth of the water bath. Such slight asymmetry of the barrelling did not appear to have a marked effect on the results, as was indicated by tests at the same temperature giving similar results regardless of slight differences in the form of the barrelling.

The elastic recovery over the initial part of the

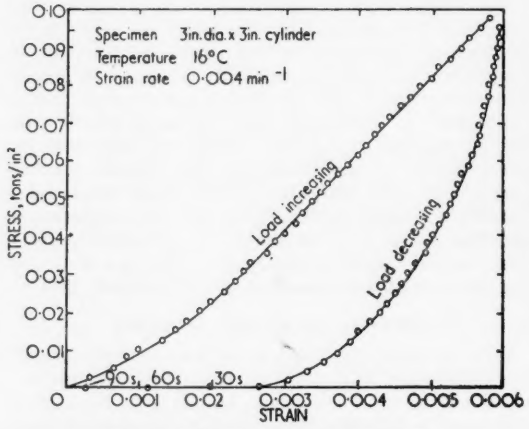
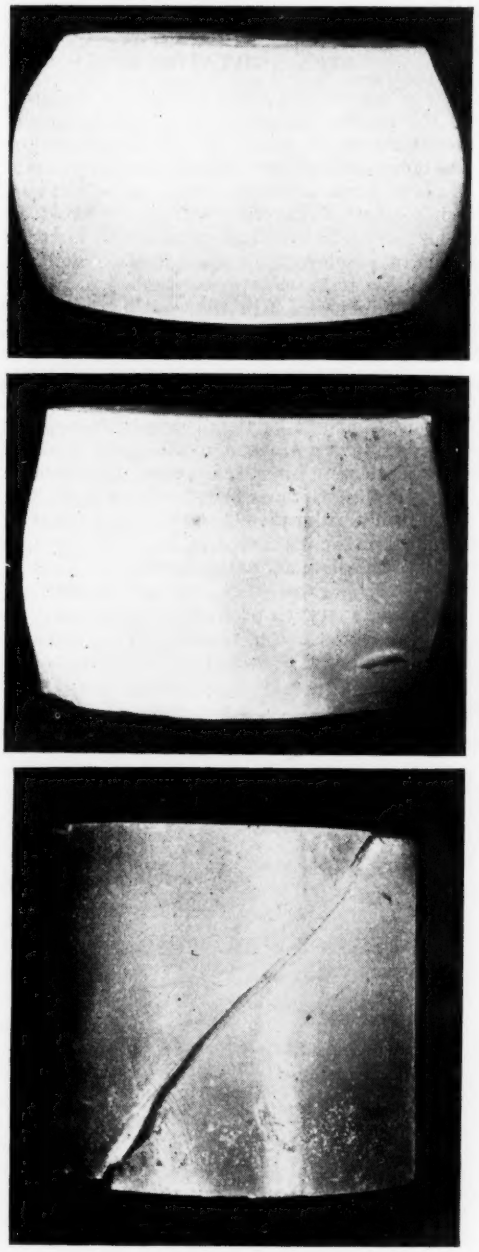


Fig. 3—Effect of stress reversal

stress/strain curve is associated with a marked hysteresis effect. This is shown by the results given in Fig. 3 for a test during which the load was removed at the same rate as it had been applied, continuous readings of strain being noted. The figures in brackets indicate the time elapsing in seconds between reversal of the load and the attainment of the various strains.

It was found that for all the specimens tested at a temperature greater than 16·1° C the material attained a condition of yielding. It is possible that the yield phenomena were due to imperfections in the cast material. This is not substantiated by the extreme consistency of the experimental results since casting defects would be expected to cause considerable scatter of the results. Several melts were agitated continuously during solidification, to ensure complete feeding, and test pieces from these melts had the same yield stress as those previously tested. The authors consider that the yielding is due to the complex structure of the paraffins. Long-chained molecules are formed, linked by comparatively weak van der Waals forces, and yielding probably occurs when the applied stress is sufficient to shear these weak linkages with subsequent reorientation of the molecules. This mode of failure is analogous to the behaviour of nylon threads[6] having randomly orientated long-chain molecules.

The post-yield behaviour depended markedly on the temperature of the test. At the lower temperatures it was found that a brittle type of fracture occurred during the period of decreasing stress immediately following the upper yield point. For the higher temperatures the material deformed plastically with consequent barrelling in a similar fashion to the test recorded in Fig. 2. For the tests where barrelling had been initiated, and particularly at the lower temperatures, failure occurred by the development of vertical cracks in the periphery of the specimen,



(*a*) Barrelling (*b*) Vertical Cracks (*c*) Brittle Failure

Fig. 4—Examples of modes of deformation in compression

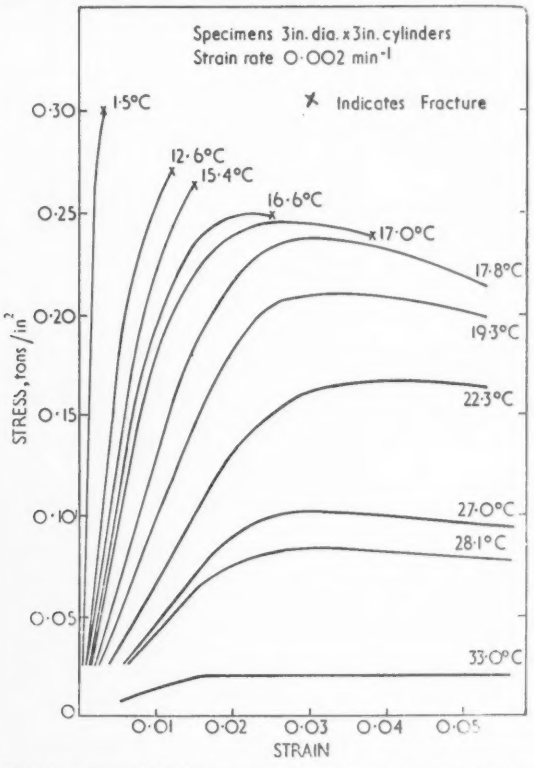


Fig. 5—Stress/strain curves at various temperatures

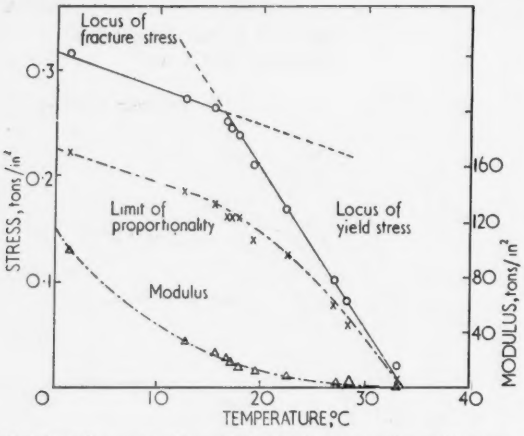


Fig. 6—The variation of physical properties with temperature

probably due to the tensile circumferential stresses in this region.

There was a marked difference when tests were carried out below 16·1° C, the curve being similar as far as the limit of proportionality, but fracture occurring before the attainment of an upper yield point. The failure in this temperature range was typical of a brittle material, the specimen shearing into two or more portions on planes at about 45° to the axis of loading. Examples of the various modes of deformation are shown in Fig. 4. A family of the stress/strain relationships at the different temperatures is shown in Fig. 5, where the scale has been chosen to illustrate the behaviour of the material in the region of yielding. (These curves have been drawn neglecting the initial non-linear portion resulting from non-parallelism of the end faces.)

The elastic modulus, the limit of proportionality and the upper yield stress, or fracture stress in the case of brittle fracture, have been derived from Fig. 5 and are plotted to a base of temperature in Fig. 6. The yield-stress variation may be represented by a straight line while for the brittle-fracture stress a second straight line intersecting the yield-stress line at a temperature of 16·1° C appears to satisfy the experimental observations. The behaviour of the material with temperature therefore appears to indicate a brittle and a ductile range in a similar fashion to the behaviour of steels. Furthermore, referring to Fig. 5, it is noted that the upper yield point becomes more pronounced with decreasing temperature, an effect which has also been noticed in tests on a variety of steels.[6]

The variation of the limit of proportionality with temperature is represented by a smooth curve, since the results do not suggest a marked transition as was found in the case of the yield stress. The modulus of elasticity also appears to vary without discontinuity.

One further point arises from the consideration of the curves in Fig. 6. An upper limit on the temperature scale for these properties appears to be approximately 35° C, whereas the melting point of the wax as determined by thermal analysis was 54·1° ± 0·1° C. Minchin[8] found a similar effect in studies of the hardness properties of paraffin waxes, the hardness falling to zero at temperatures considerably below the melting point. This he concluded was due to the presence of very small amounts of soft waxes remaining after fractionation. Paraffin waxes free from these low-melting-point constituents are not available in amounts sufficient for this type of work but the presence of such phases is not detrimental so far as this investigation is concerned.

THE FRICTIONLESS COMPRESSION STRESS/STRAIN RELATIONSHIP

The effects of the friction between the specimen and the loading platens produce a distortion of the true stress/strain relationship during compression tests on cylindrical specimens. Several attempts[9, 10] have been made to design a compression test in which the mitigating effects of friction may be avoided. The method which has been adopted in this instance was originally employed by Cook and Larke[11] during compression tests on copper cylinders.

Wax cylinders of 3 in. dia. and having heights of 6, 4, 3, 2, and 1½ in. respectively were produced. These cylinders were compressed in the testing machine at room temperature (21·1° C). The strain rate was approximately constant at 0·002 per min. To ensure constant frictional properties between the platens and the specimens, pieces of 1*F* grade Oakey emery cloth were inserted between the specimen and the platens, new pieces being used for each test.

The results from these tests for the various values of the d/h ratio are shown in Fig. 7, where d and h represent the diameter and the height of the specimen respectively. From these curves are derived the stresses necessary to produce a particular value of strain for each value of the d/h ratio. These results are shown in Fig. 8, and it is seen from them that

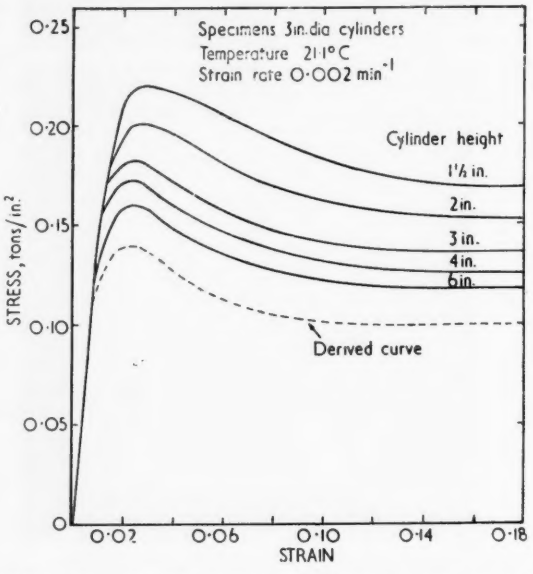


Fig. 7—Stress/strain curves for different values of d/h ratio

for any value of strain the results may be represented by a straight line. By extrapolating these straight lines to intercept the ordinate $d/h = 0$ the true stress value corresponding to the appropriate strain value is obtained. In this fashion the true stress/strain curve is derived and is represented by the dotted curve in Fig. 7. This curve shows a more pronounced upper and lower yield transition followed by plastic straining without work hardening to a strain of 18%. This does not preclude the possibility of work hardening occurring beyond this value of strain.

The following equation is given by Siebel[12] (for the idealized plastic–rigid material) as representing the conditions during the compression of a cylindrical specimen between rough platens:

$$\bar{p} \simeq \left(1 + \frac{\mu}{3} \cdot \frac{d}{h}\right) Y$$

where $\bar{p}$ is the applied stress producing the strain,
Y is the true stress corresponding to this strain,
and
μ is the coefficient of friction between the specimen and the platens.

This equation predicts that the relation between the applied stress and the d/h ratio for any particular strain is given by a straight line of slope $\mu Y/3$ and intercept equal to Y. The experimental results given in Fig. 8 are thus in agreement with this prediction although, of course, the ideal plastic–rigid material would be represented by a family of straight lines each having an intercept Y (the true yield stress) and the same slope, provided the coefficient of friction remained constant throughout the test.

The degree of adhesion and slipping in the contact zone between the specimen and the emery sheets was readily discernible from the appearance of the emery cloth after testing. Figure 9 shows a typical pattern.

At this temperature the smaller specimens developed peripheral cracks beyond 18% strain, after which value the results were no longer consistent. A further series of similar tests were carried out at temperatures

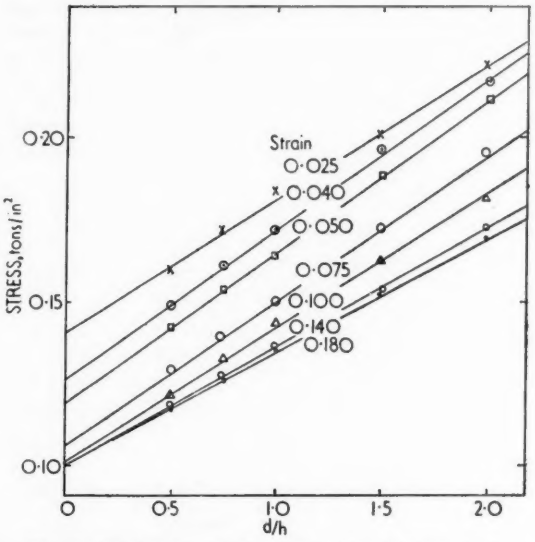


Fig. 8—Derivation of the basic stress/strain curve

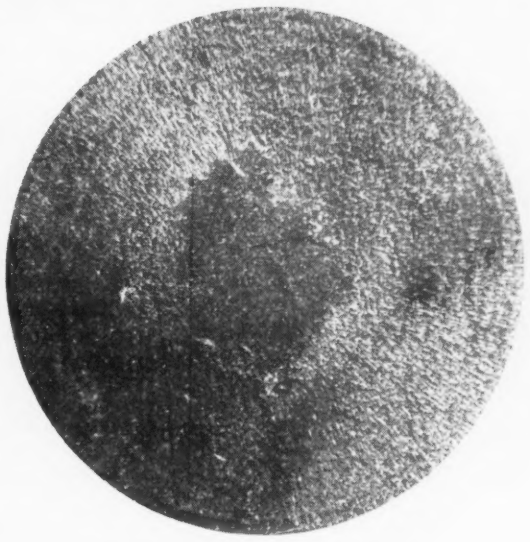


Fig. 9—Centre—region of adhesion
Outer—region of slip

of 21·9°, 24·3°, and 26·7° C. The results from these tests are shown as derived basic yield curves in Fig. 10 together with the derived curve from the previous test. These results indicate the work-hardening ability of the material at large strains and show that the rate of work hardening decreases with increasing temperature, becoming very small at temperatures of approximately 30° C. Corroboration of the ability of paraffin waxes to work-harden is given by Minchin[8] in Meyer's index for this determining material.

EFFECT OF STRAIN RATE

A few tests were carried out to ascertain the effect of strain rate on the yield behaviour and these showed a marked dependence of all the mechanical properties on strain rate. Figure 11 shows typical stress/strain curves for a series of specimens tested in air (17·7° C)

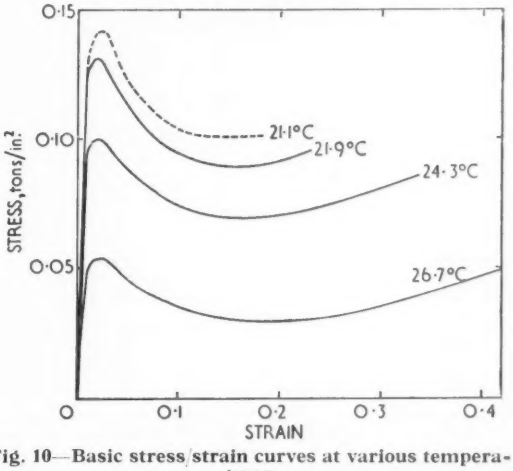


Fig. 10—Basic stress/strain curves at various temperatures

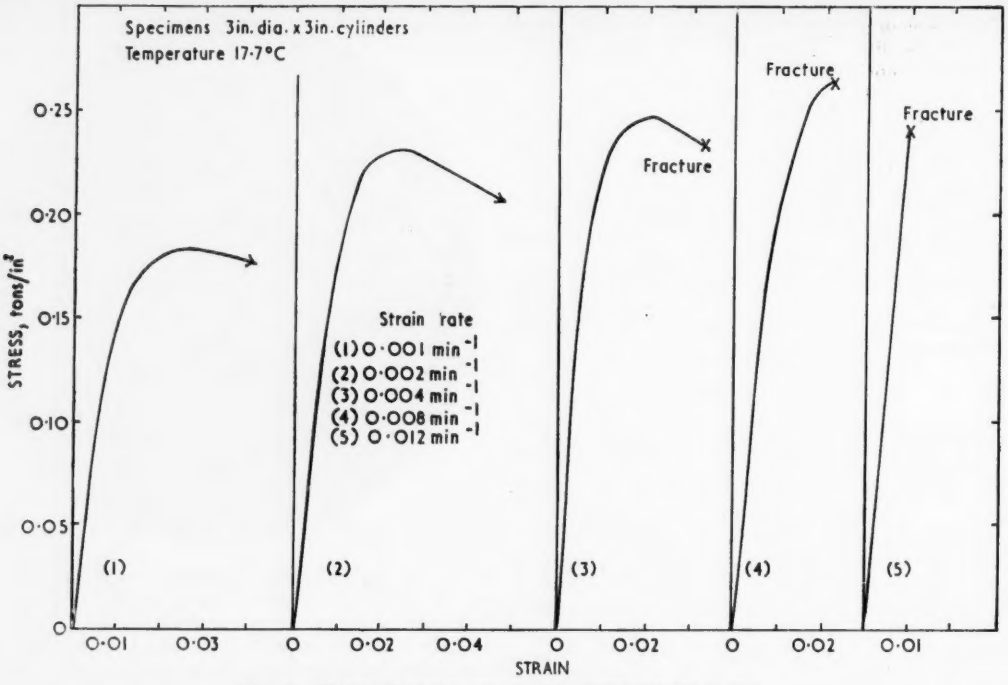


Fig. 11—Effect of strain rate on the stress/strain curve

at a variety of strain rates. The most notable feature of these results is the change from a ductile behaviour to brittle fractures, before the attainment of yield, as the strain rate increased.

The results suggest that the transition temperature of this material from ductile to brittle behaviour is strain-rate dependent. A similar dependency occurs in the case of mild steel when brittle fractures are obtained at room temperature in the case of very rapid straining (e.g. Izod test) whereas ductile behaviour has been obtained at temperatures below — 100° C for very slow (tensile) straining.[7]

CREEP TESTS

The probability of pronounced creep behaviour was suggested by the results of the load reversal test, which are shown in Fig. 3. It was apparent in this case that in the short time interval during which load reversal occurred at the maximum stress a definite creep strain was detectable before the load was decreased. Consequently a further specimen of the wax was loaded to a stress well below the yield stress and continuous readings of strain were noted with the load held constant. After a period of deformation the load was removed, at the same rate as it had been applied, and again the readings of strain were taken. The results of this test are shown in Fig. 12 where, after elastic recovery, the residual deformation is seen to agree with the measured creep at the applied loading. The progress of straining with time during the plastically deforming period is shown in Fig. 13.

Figure 14 shows the strain/time relationship for a tensile creep test at a constant stress of 0·053 tons/in². In this case the strain was measured using a Ewing's Extensometer over a 2-in. gauge length.

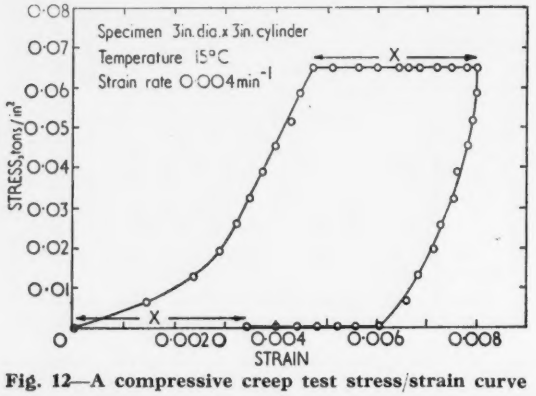


Fig. 12—A compressive creep test stress/strain curve

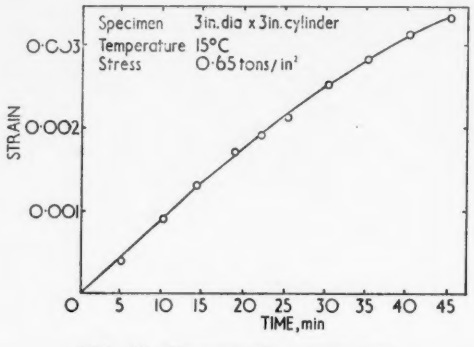


Fig. 13—Compressive creep test

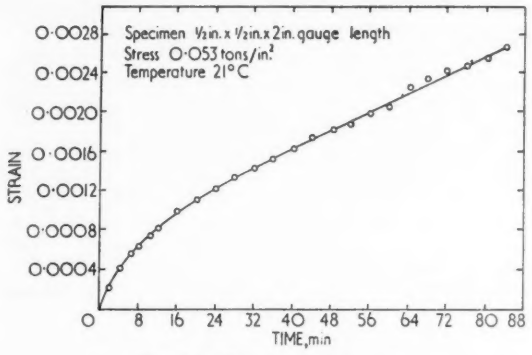


Fig. 14—Tensile creep test

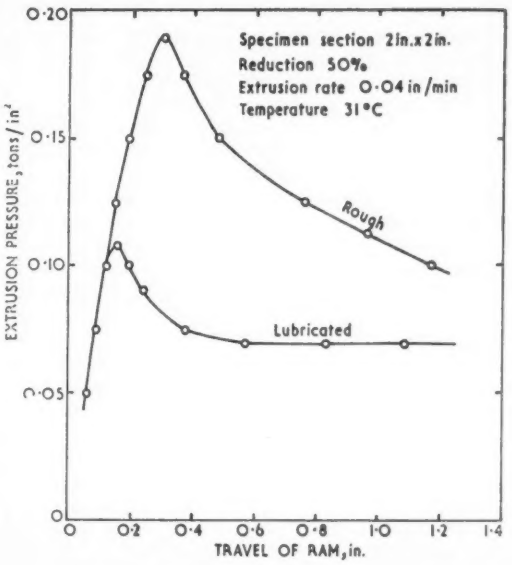


Fig. 15—Extrusion pressure curves

EXTRUSION TESTS

The following experiments on the extrusion process serve to illustrate the application of paraffin wax for the study of this type of plastic deformation.

A square block of wax was parted down the centre and a 1/10-in. square grid was scribed on one of the centre faces. This was achieved using a roller, made up of accurately spaced discs, which was drawn over the surface in two separate perpendicular directions. The grid pattern was filled with lamp black and a light coating of silicone grease was applied to facilitate the parting of the surfaces after extrusion.

The composite wax block was then extruded through a mild steel die by a ram loaded by the operating head of the standard Avery testing machine. The assembled system was held at constant temperature throughout the test by placing it in the thermostatically con-

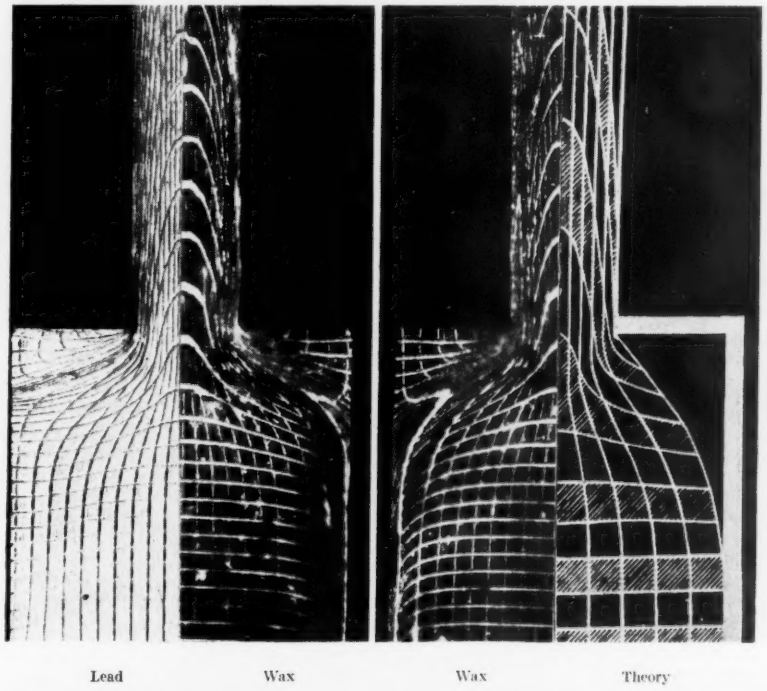


Fig. 16—Extrusion flow patterns for wax and lead, 66·6% reduction

trolled water bath. Tests were performed with lubricated and roughened walls of the container, Vaseline being used as a lubricant in the former case and the walls of the container being lined with coarse emery paper for the latter tests. The extrusion rate in all the tests was held constant at 0·04 in/min. as measured by the traverse of the ram, and continuous readings of the extrusion pressure were recorded.

Typical extrusion/load curves are shown in Fig. 15 for the lubricated wall and roughened wall conditions. The curve for the high coefficient of friction condition follows the anticipated shape for direct extrusion, the load decreasing linearly with decreasing length of the billet after an initial peak. The curve for the lubricated condition is typical of the results from inverted extrusion tests, because in this test the frictional forces between the billet and the container walls are small. In both these tests the extrusion was halted before the end effects became apparent in order to preserve the steady-state flow pattern. The container was dismantled and the wax was allowed to cool to room temperature before the two halves of the billet were separated, thus ensuring no distortion.

Since paraffin wax is translucent, the grid patterns could be accurately recorded by holding a piece of high-contrast contact printing paper against the pattern and illuminating through the wax.

A lead billet was scribed with a similar grid to that used for the wax specimen and was extruded from the same die at a temperature of 230° C. (The elevated temperature was necessary to prevent undue strain being imposed on the existing die assembly.) The flow patterns for the lead and wax for a 66·6% reduction are compared in Fig. 16*a*, the frictional conditions being similar in each case. There is excellent agreement between these two patterns and reasonable agreement is also obtained for the comparison with the theoretical pattern[1] shown in Fig. 16*b*.

Although a satisfactory grain boundary etchant has not yet been obtained, a structure can be displayed by etching the wax with benzene containing a nigrosine-base dye. Figure 17 shows the structures obtained

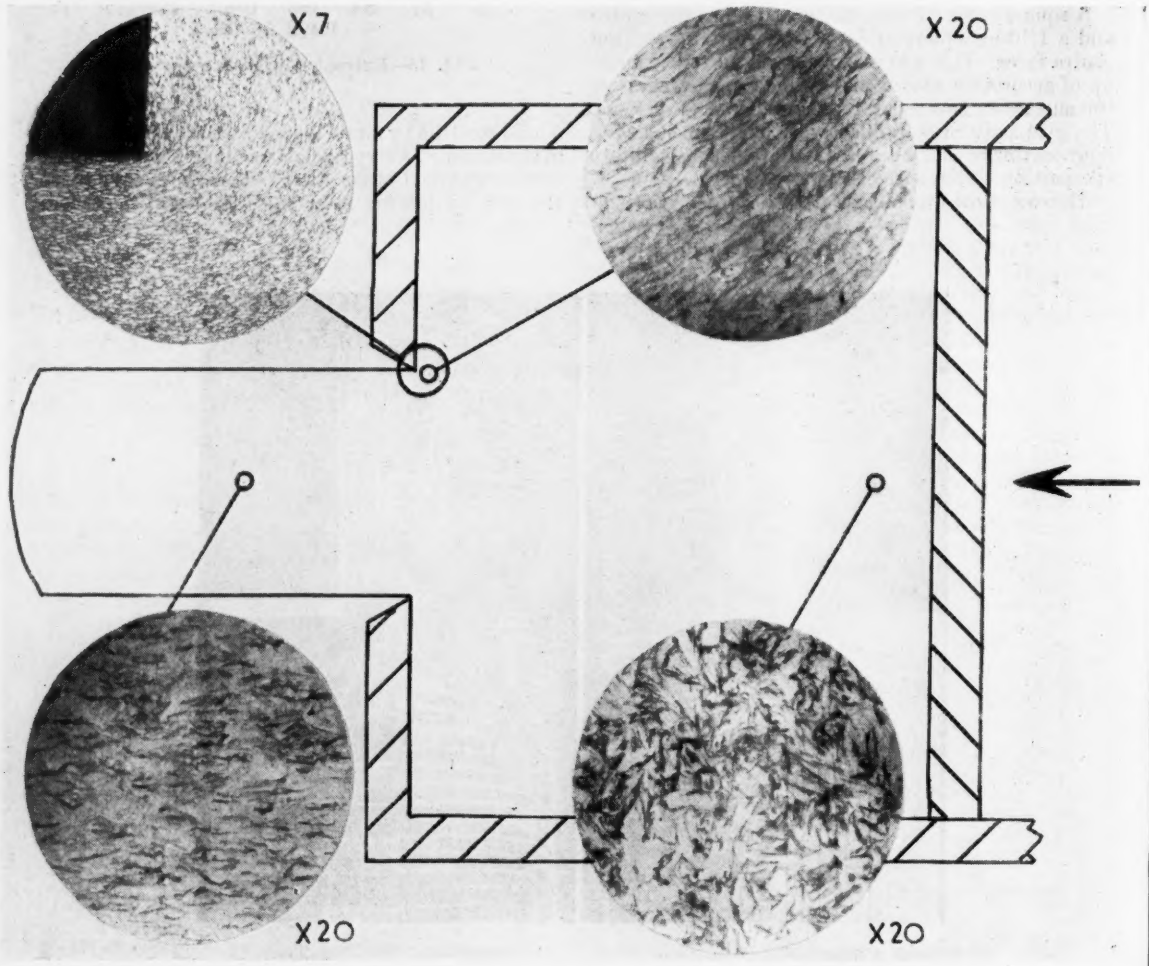


Fig. 17—Etched structures at various points in a wax extrusion, 66·6% reduction

at several locations in a partially extruded block. These photomicrographs were obtained using a Vickers projection microscope with transmitted light. The change from the undeformed to the deformed regions is at once apparent as also is the extent and direction of the deformation. Although these structures have not yet been fully interpreted, in view of their behaviour on deformation they are presumably related to the crystalline nature of the wax.

CONCLUSIONS

The results of the tests described in the foregoing indicate the similarity between the mechanical properties of paraffin wax and metals. These results are by no means exhaustive but are intended primarily as an indication of the variables which must be considered when using paraffin wax models. They also suggest several more detailed investigations for the study of the behaviour of metals, e.g. the study of hysteresis effects, strain-rate effects, and the variables governing the ductile/brittle behaviour of metals.

The design of simple experiments for demonstration of the fundamental properties of materials is one further application of the technique which should prove most profitable. Such phenomena as the creep behaviour of material can be simply demonstrated on standard apparatus in relatively short time intervals.

The experiments carried out on extrusion suggest that paraffin wax has four salient advantages as a model material for the investigation of the deformation processes. These advantages are: (*a*) ability to produce accurate patterns of the mode of deformation; (*b*) ease of preparation of complex shapes by virtue of the good machinability and forming properties of the material; (*c*) production of useful information relating the applied forces and the extent of deformation; (*d*) correlation of change in microstructure of the material with the extent of deformation.

Acknowledgments

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An Electrical Analogue for Estimating Die Temperatures During Wire Drawing

By A. E. Ranger, B.Sc., A.Inst.P.

SYNOPSIS

Previous attempts to measure die and wire temperatures have not produced reliable data; in this investigation a new method has been used with considerable success. Temperatures of the outside of the die pellet were measured during wire drawing, and the temperatures of the interior surface of the die in contact with the wire were then computed by means of an electrical resistance network analogue of the thermal system. The most significant finding is that external cooling of the die is far less important than cooling its inlet, to prevent overheating of the soap powder before it enters the die.

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PROBLEMS OF STEADY-STATE HEAT CONDUCTION can frequently be solved by the use of an electrical resistance network analogue. The behaviour of the network can be described by the finite difference form of the heat conduction equation ($\nabla^2\theta = 0$). Hence the network must be regarded as providing an approximate solution only, although the error from this source may be reduced to any required magnitude by appropriate reduction of mesh size.

A two-dimensional network with suitably graded components may be used to solve three-dimensional problems involving radial symmetry. Such a problem occurs in wire drawing.

In this process the wire diameter is reduced by drawing through a truncated cone-shaped die as shown in Fig. 1. The speed of drawing varies from a few hundred to several thousand ft/min, depending on wire size and material. Although the wire is lubricated, the combination of high contact pressures and drawing speeds causes high temperatures at the face between the die and the wire (subsequently referred to as the interface), and it is generally agreed that these temperatures are the cause of many of the diffi-

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The author, formerly of B.I.S.R.A., is now with Bowater's Development and Research, Ltd.

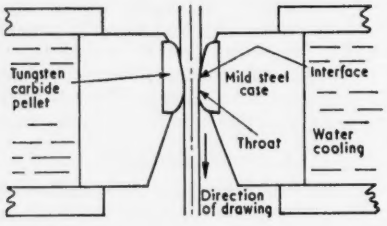

Fig. 1—Wire drawing process

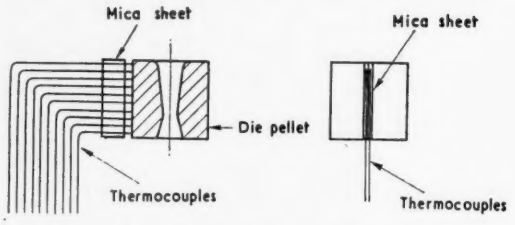

Fig. 3—Fitting of thermocouples to pellet

culties which prevail in modern high-speed practice. It is therefore of great importance to know what these temperatures are under various drawing conditions and what may be done to reduce them.

Direct measurement is difficult for three main reasons. First, the material of the die pellet (sintered tungsten carbide) is not an easy one in which to embed thermocouples, and the use of a more tractable material is not usually feasible. Secondly, the area of the interface is usually very small; and thirdly, this is a region of very steep temperature gradients.

Previous experimenters, therefore, have usually been content to measure some general temperature, say at a point in the die case, or an average interface temperature by using the whole of this surface as the hot junction of a thermoelectric circuit.

Kopczynski and Hoggart,[1] however, used the method due to Reichel,[2] in which the die is constructed from two dissimilar metals, the region of contact being confined to a narrow annulus at the die throat. The whole die forms part of a thermoelectric circuit measuring the maximum interface temperature. Even this limited aim may not be achieved with sufficient accuracy, however, because of the necessarily finite size of the hot junction and the steepness of the temperature gradients in this region.

The method described below overcomes this difficulty and in addition yields a complete temperature distribution both along the interface and throughout the body of the die.

Briefly, temperature distributions are obtained experimentally for the outside surface of the die pellet under various drawing conditions. In addition the total heat flux through the die (with the exception of a small loss due to convection which is allowed for) is measured. These two sets of measurements enable the temperature distributions throughout the die to be computed with the aid of the analogue network.

DESIGN AND CONSTRUCTION OF DIE AND THERMOCOUPLES

Figure 2 shows the design of the special die case used in the experiments. The pellet fits inside the two halves, which are located with pins. The halves are tapered to fit into a similarly shaped cylinder, the direction of taper being such that the drawing pull tends to force the two halves together. One half is grooved in the manner shown to a depth of 0·020 in., to allow the thermocouple wires to be accommodated.

The thermocouples were constructed from 40 s.w.g. copper and constantan wires. Correct spacing of the wires was first achieved by cementing them to thin mica spacers (Fig. 3). The complete assembly was then soldered to the pellet (previously copper-plated) with a high-melting-point soft solder.

To be successfully represented by a two-dimensional network, the heat flow must possess radial symmetry. It was to minimize the disturbance to this symmetry that the thermocouple system was made so thin. A further requisite is good thermal contact between the components of the die, and especially between the pellet and the case. Accordingly, all these items were copper-plated on their mating surfaces, and, immedi-

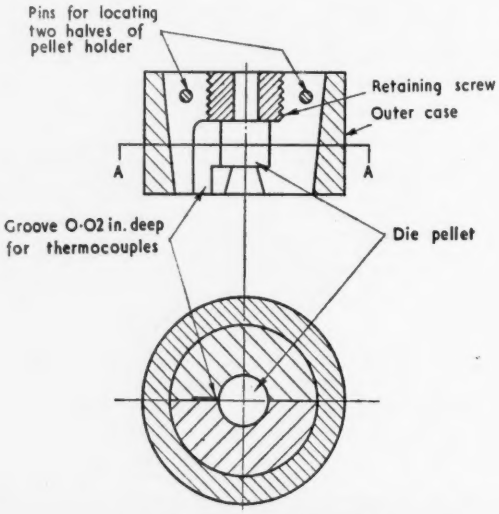

Fig. 2—Die case assembly

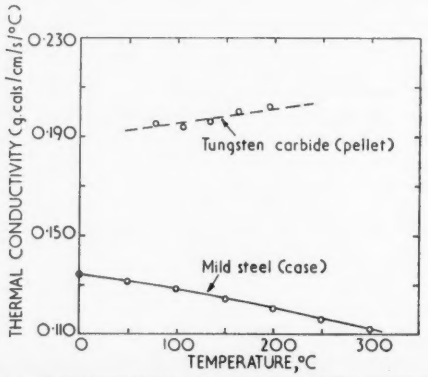

Fig. 4—Conductivities of case and pellet materials

ately prior to the drawing experiments, they were amalgamated with mercury and assembled.

THE ANALOGUE NETWORK

The general principles of analogue networks have been adequately discussed in literature, and an excellent introductory article by G. Liebmann[3] includes an extensive bibliography. The present network is quite orthodox, except that the mesh is much finer in the region of the interface, where the temperature gradients are steepest.

As well as grading the resistance values previously mentioned, it is also necessary to make allowance for the difference in thermal conductivities between the two materials of the die. Since little information is available on the conductivity of tungsten carbide, this was measured by a standard method using a specimen sintered and prepared under the same conditions as the experimental pellet. The results are plotted in Fig. 4, together with data for the mild steel from which the case was constructed.

With a simple network it is, of course, necessary to estimate in advance the average thermal conductivities under operating conditions, which implies estimating average temperatures. For the case and pellet respectively these figures were 75° C and 175° C, and it will be seen from the results that these estimates are not sufficiently out to cause serious error.

The temperature of the die cooling water is the 'zero' level from which other temperatures are initially measured, and this corresponds to earth potential on the network. The outer surface of the die case is above this temperature however, owing to the existence of a film of slowly moving water which surrounds it. An appreciable temperature drop occurs across this film, sometimes known as the stagnant layer. The purpose of the row of variable resistances *A* (Fig. 5) is to simulate this layer. Row *B* enables various potential (temperature) distributions to be set up along the interface. The bank of resistances separated from the main network provides a leakage path for current, corresponding to the loss of heat to the atmosphere by convection from the rear of the die. The values of these resistances were calculated on the basis of a separate experiment, in which the rate of loss of heat by free convection from similar metal surfaces was measured directly.

During drawing, the die entrance rapidly fills with soap powder. Since this has a very low thermal conductivity, it is assumed that there is no heat flux across this part of the die surface. In addition, the front and back flat surfaces of the die were insulated with fibre sheet and no heat flow assumed.

It should be pointed out that although the values of the resistances *A* are initially unknown, each represents the thermal resistance of a known proportion of the stagnant layer, and their relative values are consequently known and remain unaltered. Thus the whole set of values effectively constitutes only one unknown quantity.

DRAWING EXPERIMENTS

Predrawn mild-steel wire was drawn from 0·116 in. diameter to 0·100 in. through a directly-cooled

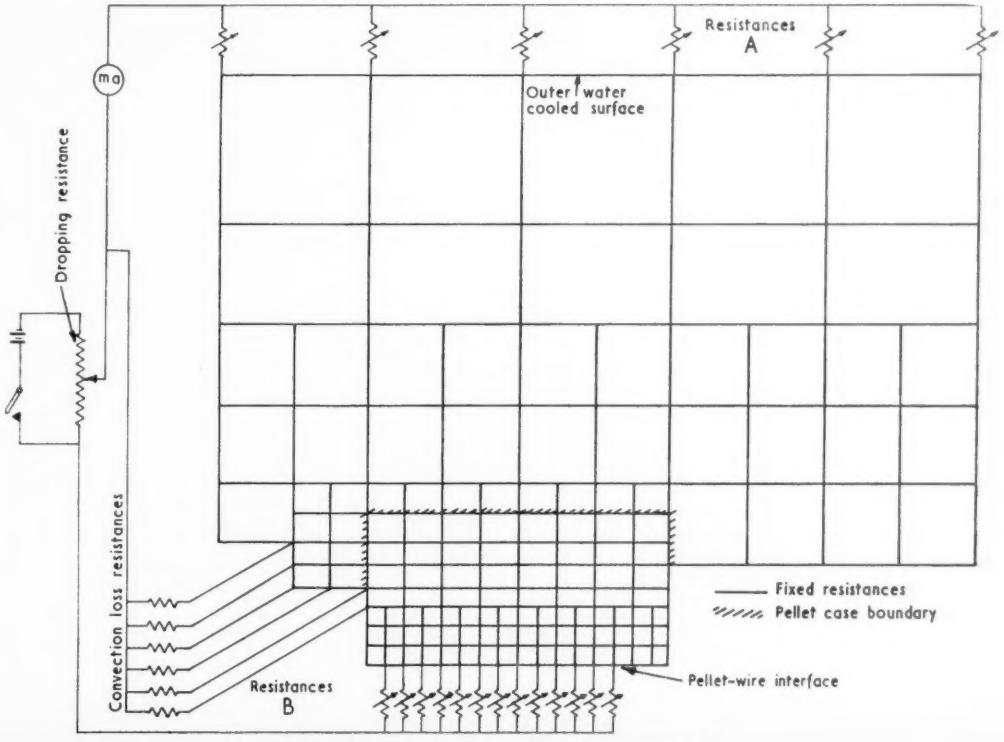

Fig. 5—Circuit diagram of analogue network

tungsten carbide die of 2½° semi-angle with Wyrex soap as the lubricant. Alignment of wire and die was maintained by a guide die of 0·150 in. diameter preceding the drawing die. The experiment was in two parts, the first serving to measure the effect of varying the flow of the die cooling water, and the second, the effect of drawing speed.

Drawing was commenced at 200 ft/min with the cooling water flowing at 0·2 gal/min. After sufficient time had elapsed for equilibrium conditions to be attained, the e.m.f.'s from the thermocouples (including a differential couple in the cooling water system) were measured. This was then repeated for flow rates of 0·4, 0·6, 0·8, and 1·0 gal/min, all at 200 ft/min and each time allowing equilibrium conditions to become established before taking the readings. When this series of measurements had been completed, the drawing speed was increased in discrete steps to 500, 900, 1400 and 2000 ft/min, with the cooling water steady at 1·0 gal/min throughout. At each speed all thermocouple e.m.f.'s were measured under steady conditions. Finally, the speed was increased to 3000 ft/min but only one temperature reading was obtained before the wire fractured. Subsequent examination showed that lubrication had been good throughout the experiment and fracture occurred soon after the first signs of lubricant breakdown.

USE OF THE COMPUTER

The heat flux through the die for each set of conditions was first calculated from the temperature rise of the water and the flow rate. The resistances A were then set at a trial series of values, and the resistances B adjusted until a potential distribution along the outer surface of the pellet was obtained which corresponded to the first experimental temperature distribution. The current through the network was then observed and compared with the heat flux for this case. If the former was too high, the resistances A were increased and if too low they were decreased. This sequence (first adjusting A and then B) was repeated until both the outside pellet distribution and the current were simultaneously correct.

When the network was correctly adjusted the potential distribution along the interface was read off, giving the temperature along the working surface. The potential could be measured at every point inside the die, but this complete distribution was only obtained for one set of conditions (1400 ft/min and 1·0 gal/min).

Having obtained all the information for one set of conditions, the whole process was repeated for each set in turn.

FINDINGS

Figures 6 and 7 show the variation of temperature along the interface for all the conditions examined, from which it is evident that the temperature at the interface increases substantially from wire inlet to outlet, increases with speed and decreases with improved die cooling. Die cooling is not as effective as is commonly believed; indeed, as is shown by Fig. 8, the limit to what can be achieved by this type of cooling was almost reached in the experiments.

The complete temperature distribution in the interior of the die for stated conditions is shown in Fig. 9. This shows, among other things, that, whereas

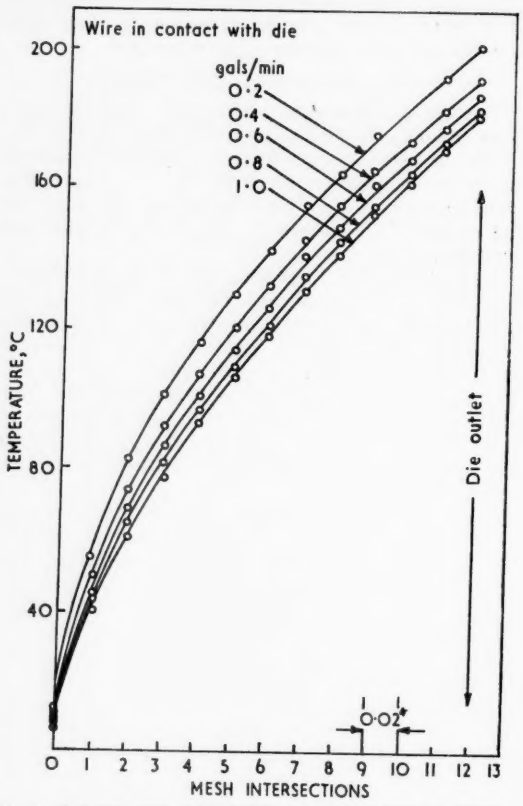

Fig. 6—Dependence of interface temperature on water cooling

on the whole heat flows from the wire to the die, close to the point of wire entry a reverse flow takes place.

DISCUSSION

A theoretical analysis of temperature distribution along the interface made by Siebel and Kobitzsch[1] leads to the expression for the temperature rise:

$$\theta = \frac{V\epsilon}{J\rho s} = 1{\cdot}22m\,\frac{\mu Y}{J}\sqrt{\frac{Vl}{\rho s k}}$$

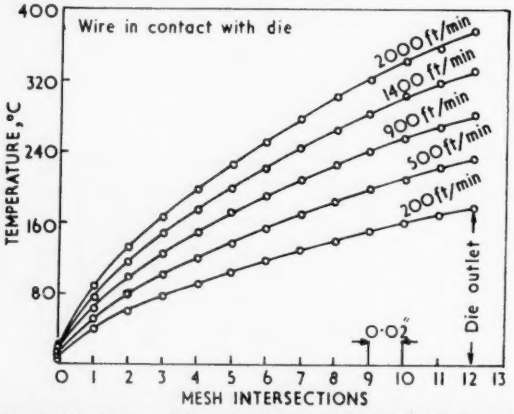

Fig. 7—Variation of interface temperatures with speed

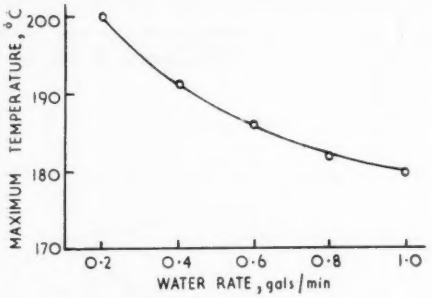

Fig. 8—Effect of die water cooling

where Y = mean yield stress of the wire
ϵ = deformation ($\ln A_1/A_2$ where A_1 and A_2 are cross-sectional areas of the wire before and after drawing)
J = mechanical equivalent of heat
ρ = density of wire
s = specific heat of wire
m = mean fraction of frictional heat retained by the wire
μ = coefficient of friction
V = drawing speed
l = distance along interface from point of first contact between wire and die
k = thermal conductivity of wire

The first term represents the temperature rise due to wire deformation alone and may be readily calculated provided the mean yield stress is known. This can be obtained from tensile tests on the wire before and after drawing, but one must allow for the much higher strain rate prevailing during drawing. The mean yield stress of the wire as measured by tensile tests was 40·0 tons/in², corresponding to a temperature rise of 48·1° C; allowing for the strain-rate effect, with the help of Nadai and Manjoines' data[5] this becomes 63·2° C at 200 ft/min and 69·2° C at 2000 ft/min.

After subtracting the appropriate temperature rise due to deformation from each distribution, the resultant temperatures were plotted against a 'length factor' which, in addition to the square root of the length along the interface, also includes two correction terms allowing for the work-hardening of the wire and its acceleration as it passes through the die. It will be seen that there is still a significant curvature (Fig. 10) which might be expected, since one of the major simplifications of the theory is the assumption of a constant coefficient of friction. The curvature is also apparent when the maximum throat temperatures are plotted against the square root of the drawing speed (Fig. 11). There is mounting evidence that lubrication in wire drawing is quasi-hydrodynamic in nature, and accordingly the coefficient of friction may be expected to decrease with temperature. If the theory is assumed to be substantially correct, then the equation may be used to calculate the small variation of frictional coefficient with temperature. Figure 12 shows the result of this procedure, and whilst the

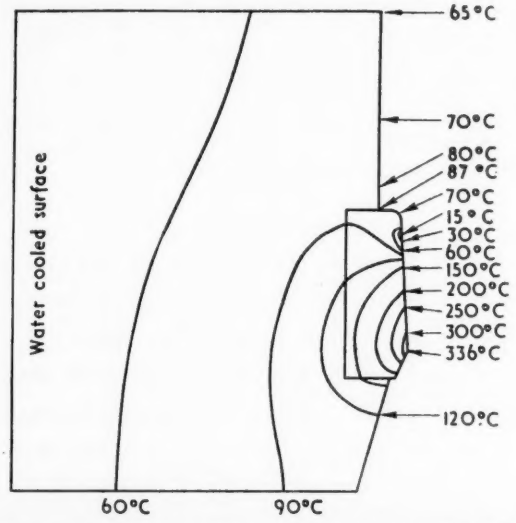

Fig. 9—Temperature distribution in die at 1400 ft/min

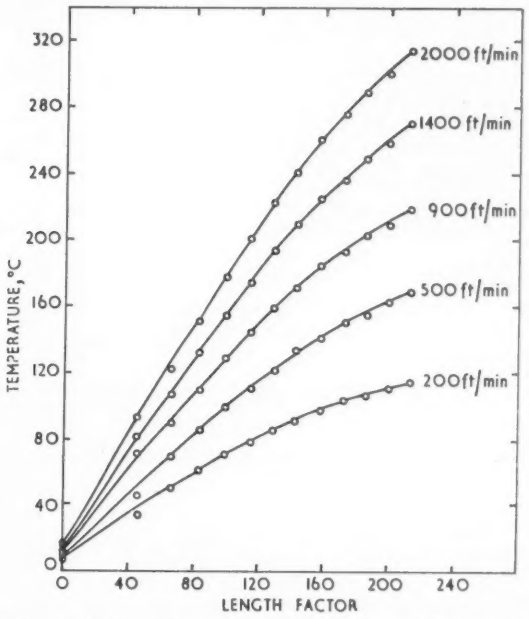

Fig. 10—Comparison of Siebel's equation with experimental results

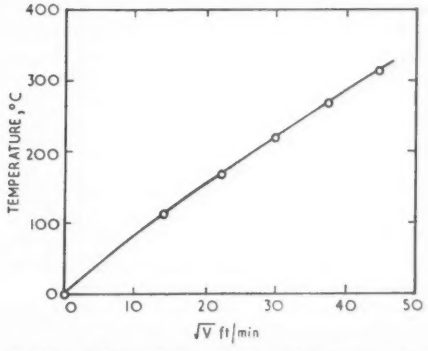

Fig. 11—Variation of maximum throat temperature (frictional heat only) with drawing speed

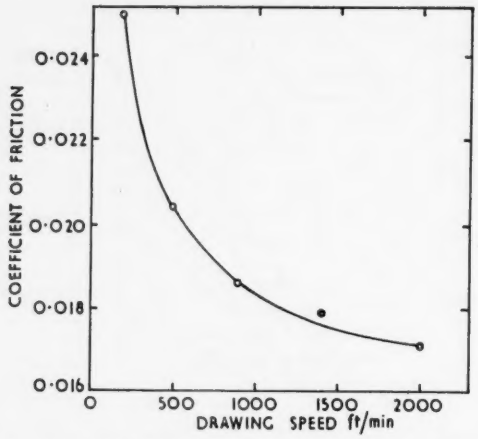

Fig. 12—Variation of coefficients of friction with drawing speed

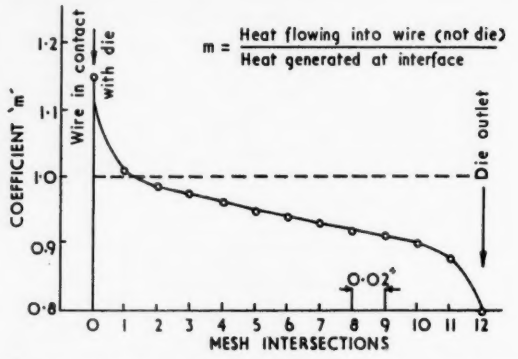

Fig. 13—Variation of heat partition coefficient along pellet–wire interface

accuracy is limited it does show a considerably smaller magnitude of coefficient than is usually obtained at lower speeds. When using the equation it is usual to assume that the value of 'm' is constant along the interface. Figure 13 shows that this is a reasonable approximation.

One of the most interesting results of the experiments is the value of 380° C for the maximum throat temperature at 2000 ft/min. It must be emphasized that at this speed lubrication was perfectly satisfactory, breakdown only occurring after several minutes of drawing at 3000 ft/min. It is therefore apparent that the temperature of the lubricant in the die may be far greater than could be tolerated by the same soap under laboratory conditions. There are three possible reasons for this. First, the wire passes through the die in a matter of milliseconds and the increase in temperature occurs within this period. As the wire leaves the die the temperature gradient from its surface towards the centre is exceptionally steep and this produces a very rapid initial cooling of the surface. Both heating and cooling of the lubricant, therefore, occur extremely rapidly and little time is allowed for any chemical changes to take place. Secondly, the high pressure at the interface can appreciably influence changes of state, in particular melting. Thirdly, for a large proportion of the time for which the soap is subjected to high temperature, it is effectively sealed from the atmosphere.

Another point which emerges, which is of considerable interest to the practical wire drawer, is the comparatively small effect on interface temperature of quite large variations in die cooling. This, at first sight, conflicts with industrial experience that efficient die cooling is frequently of genuine value. Attempts to dispense altogether with cooling have usually met with failure, although the present experiments indicate that the interface temperatures cannot be very much increased under these conditions.

Figure 9, however, shows that the temperature of the case surface in the region of the wire entry may rise 70–80° C above room temperature at 1400 ft/min even under conditions of good water cooling. Since the lubricant may dwell in this zone for some time, it is apparent that it may also be preheated by the die case. By drawing wire slowly through an externally heated die, Ranger and Wistreich[6] have shown that the lubricant film thickness rapidly decreases when the temperature of the die as a whole is raised, and complete breakdown of the film and severe damage to wire and die occur at maximum throat temperatures of no more than about 180–190° C. This is further evidence in favour of the quasi-hydrodynamic picture of the lubrication process, and indicates that the temperature of the die case, and of the region around the wire entry in particular, may be more important than the maximum throat temperature. If this is indeed the case then attention might profitably be paid to the problem of cooling the front surface of the die more effectively than is done at present.

Acknowledgments

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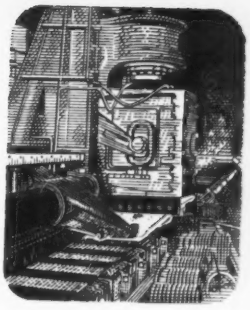
IRON AND STEELWORKS ENGINEERING

The Iron and Steel Engineers Group



Lubrication in Iron and Steelworks

By H. Jones and G. D. Jordan

SYNOPSIS

Part I of the paper, in discussing lubricants, considers the influence of certain physical and chemical characteristics upon their performance in service. It is suggested that the control of lubricants in an industrial unit is achieved by a method of classification according to usage and by limited specifications. The experiences of a major consumer following this procedure are discussed and the resulting improvements are outlined. The use of colour coding as a further method of control is also mentioned.

Part II of the paper deals with the application of lubricants. Lubrication systems are classified and their general features are outlined. Typical applications in certain sections of the industry are treated in some detail, and a suggestion is made for improving the lubrication of heavy melting shop overhead-cranes. 1380

Part I—THE ROLE OF LUBRICANTS

IT IS SOME TEN YEARS since a paper[1] was presented to The Iron and Steel Institute on a subject as comprehensive as that implied by the title of this paper. During the intervening period, steady progress has been made in the subject and it is most appropriate in a year when there is a Conference on Lubrication and Wear* that the present-day position of lubrication engineering in iron and steelworks should be reviewed. Although this paper is confined to the iron and steel industry, nearly all facets of the subject are embodied in the wide experience of that industry.

It is significant that at the time the earlier paper[1] was presented there were no lubrication engineers employed directly by industry in this country. Much of the subsequent discussion at that time was centred around this point and it was undoubtedly partly as a result of these discussions that specialist engineers were appointed. The justification for such appointments is mirrored by a steady growth in numbers and a management belief in their value.

It would perhaps be opportune to define the duties of a lubrication engineer in the U.K. although the degree and nature of responsibility varies widely.

The American Society of Lubrication Engineers has defined the lubrication engineer as:

". . . a person who, by professional training or equivalent experience, is qualified to apply the knowledge of engineering to the field of lubrication or lubricating sciences. He may be active in research, development, application, service and maintenance, consulting, technical sales, writing or teaching. In these activities, his responsibilities may involve direct or indirect participation in mechanical design, lubrication economies, lubricant formulation or application, recommendations of all forms of lubricants in all types of equipment, machines, or products with the objectives of obtaining optimum conditions with regard to wear, friction, power, corrosion, leakage, vibration, or other operating characteristics influenced by the lubricant. He is familiar with and may plan, participate in or supervise lubrication tests, practices, procedures, schedules, standards, requirements and/or other work involving lubricant storage, dispensing and reclaiming equipment."

It is beyond the scope of this paper to attempt to detail the many features embodied in this definition, and reference can only be made to some recent articles[2, 3, 4] on the subject.

CONSIDERATION OF PLANT AND LUBRICANTS

In considering the diversity of plant and corresponding lubricants in iron and steelworks, the range of operating conditions varies within extremes of temperature, load, and speed: e.g. variations in temperature between bearings on the door operating gear of an O.H. furnace and an outdoor E.O.T. crane under winter conditions, or variations in load between

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Mr. Jones is Lubrication Engineer at the Appleby-Frodingham Steel Company and Mr. Jordan is with the United Steel Companies Department of Operational Research and Cybernetics.

a wide plate-mill roll-neck bearings and the bearings on an M.G. set, or the variations in journal speeds between, say, a drum-type ore dryer and a high-speed tandem strip mill.

Again, not only must pure lubrication be considered, but also process lubricants and petroleum derivatives such as roll oils, rust preventives, electrical oils, etc.

In the past, each piece of plant has brought new lubrication problems with it and in selecting lubricants, operators have been subject to external pressures both from the plant manufacturer and the lubricant supplier. The affect of ' sole recommendations ' has been devastating to any inventory control, and the situation can be further aggravated by the not unusual practice of plant manufacturers changing course in mid-stream and transferring their favours from one lubricant supplier to another. It is the absence of generally accepted standards which forces the user to depend either on machine makers' or lubricant suppliers' recommendations.

Characteristics Influencing the Evaluation of Lubricants

Lubricants are almost universally marketed under brand names, a practice which apart from identifying the supplier with a particular product, will undoubtedly assist him materially in the advertising, accountancy, and general book-keeping of his business. This system of nomenclature, however admirable from the supplier's point of view, affords the user very little assistance in assessing the character of the product or its purpose. The addition of the terms ' light,' ' medium,' ' heavy,' etc., to the brand-name does very little to clarify the position, as such terms do not always imply a fixed quantitative value which can be equally applied to the various brands of one company, much less so to the equivalent brands of various companies.

It is interesting to note this same ambiguity in B.S. 210, where ' light ' in group *1* covers a viscosity range of 12·6 to 17·1 cS at 140° F, whereas in group *5* the range is 23·4 to 38·4 cS at the same temperature.

To avoid the complications which can arise from too-rigid adherence to machine-makers' recommendations, or from the restriction implied by acceptance of those of a single supplier, major consumers, including many of the larger iron and steel companies, adopt a policy of inviting several selected lubricant suppliers to submit a list of products suited to the needs of the plant and, at the same time, to give the characteristics of the lubricants offered. This system permits the submission of branded, unbranded, or specialized grades and affords the user the opportunity of assessing their relative merits.

Standard test procedures have been laid down for the assessment of these characteristics and results obtained in the prescribed manner are considered strictly comparable. For lubricating oils, those most frequently quoted are: specific gravity, flash point, pour point, and viscosity. These are held in common by all oils, and are consequently regarded as the primary or basic properties. The tests for them are non-destructive and are carried out directly on the sample without use of reagents, reactants, diluents, etc.

Specific Gravity (*I.P.* (*Institute of Petroleum*) *test* 59/55)—The specific gravity of an oil is affected by the presence of such naturally occurring constituents as asphalt, resins, waxes, etc. Consequently the refining processes to which it has been subjected will have had some influence on its final value.

Considered alone, the specific gravity of a mineral oil affords very little information of its suitability for a particular application. Modern refining methods have reduced some of its former significance as an indicator of origin and quality, but it is still found that when comparing otherwise similar oils, the one with the lowest gravity usually has the best natural oxidation stability.

Flash Point (*I.P. tests* 34/55 *and* 35/42)—Lubricating oils are produced from that part of crude petroleum left after the gasoline, kerosene, and diesel fuel have been extracted. The residual is further fractionally distilled to produce the stocks from which the various blends or grades are constituted. The lighter or lower viscosity stocks are produced at the lower boiling point, and the heavier or more viscous stocks at the higher boiling point. As the flash point is the temperature to which an oil must be raised before it evolves sufficient vapour to form a mixture with air capable of causing a small explosion when brought into contact with an open flame, it will in some measure reflect the care with which the base stocks have been prepared and the skill with which they have been blended. Naphthenic oils have lower boiling points than those of paraffinic origin but to offset this, the former leave a lesser amount of objectionable carbonaceous deposits. These factors must be considered in relation to the purpose for which the oil is intended if a sound assessment is to be made.

Pour Point (*I.P. test* 15/55)—The presence of naturally occurring waxy materials which solidify when an oil is cooled, cause it to gel and interfere with its ability to flow so that under low pressure it will not flow at all. The temperature at which, due to this cause, the oil just barely flows is known as the ' pour point,' and pour points as high as 50° F are quite common amongst the heavier oils. Oils, particularly those extracted from paraffinic crudes, are de-waxed to improve their low-temperature fluidity. This may also be improved by adding substances which modify the crystalline structure of the chilled waxes and prevent or postpone gelling. These pour-point ' depressants ' make it possible to leave in more of the waxy elements which have a beneficial effect on the viscosity/temperature behaviour of the oil.

As oils made from naphthenic crudes contain very little wax, they have naturally low pour points, hence their preference for very low-temperature operation. While bulk oils can be poured and pumped at temperatures lower than their recorded pour points, this test has such practical significance that in certain defence specifications (e.g. MIL–0–2104A) its determination is called for after varying degrees of exposure to low-temperature conditions.

Viscosity (*I.P. tests* 70/55 *and* 71/55*T*)—Viscosity, which can be defined as the ' internal frictional

resistance offered to the change of shape or relative motion of its parts,' is fundamentally the most important property of a lubricating oil as both film thickness and friction vary directly with it. For efficient operation it is necessary not only to maintain a hydrodynamic film but also to hold to a minimum the power losses which rise with increasing viscosity. Figure 1 shows the characteristic form of the resultant curve when the coefficient of friction for a particular bearing is plotted for different conditions of load, speed, and oil viscosity.

The viscosity of all lubricating oils changes markedly on heating or cooling but not necessarily to the same extent, so that the viscosity at service temperatures must be known.

The viscosity index or *V.I.*, based on the relation of the viscosity of an oil at 100° F to that at 210° F, is used to rate numerically this viscosity/temperature characteristic so that higher numbers denote lesser change. Another system of defining viscosity/temperature characteristics which is favoured by some large users is the ' viscosity ratio.' It concerns the viscosity at two temperatures, usually 70° and 140° F or 140° and 200° F, according to the purpose for which the oil is required. It is arrived at by dividing the viscosity at the lower temperature by that at the higher, and conversely to the *V.I.*, larger numerical values denote greater changes.

The inferences to be drawn from an examination of the foregoing physical properties apply equally to most lubricating oils irrespective of their application. Of the laboratory tests designed to predict the possible behaviour of oils under specific service conditions, those concerned with emulsifying and water-separating characteristics, oxidation stability, acidity, and foaming will be of interest to steelworks engineers.

Demulsification Number (*I.P. test* 19/55)—Lubricating oils used in iron and steelworks are frequently exposed to contamination by water, and those which will not readily separate from it tend to form harmful emulsions. The demulsification number, which is the time in seconds for an oil to separate when emulsified and allowed to separate under prescribed conditions, affords an indication of its possible behaviour in the presence of water or steam. If an oil has a good demulsification number when new, its ability to maintain this property in service largely depends on its oxidation stability.

Oxidation stability (*I.P. test* 48/55)—All lubricating oils are deteriorated by the action of oxygen, producing petroleum acids and sludge which tend to stabilize any emulsions formed. This action is normally slow but is influenced by the degree of refining, the catalytic action of metals or other contaminants, and by temperature. Of these, heat has the greatest effect and it is claimed that above about 160° F, the rate of oxidation doubles with each 18° F temperature rise. The oxidation characteristics of an oil can be assessed by comparing the viscosity and carbon residue of a sample through which air has been blown, with that of the original oil.

Neutralization Value (*I.P. test* 1/55)—The acid content of an oil increases with progressive oxidation and a knowledge of the neutralization value of a new oil will allow the rate of deterioration to be followed. It is expressed as the number of milligrams of potassium hydroxide required to neutralize a gram of sample, and many specifications quote a limiting maximum neutralization number. For new, unused straight mineral oil it should be negligibly small, but for all compounded and some additive oils it can have a positive value. More important than the acidity of an unused oil is its rate of increase in service, as rapid increases usually precede formation of sludge.

Foaming tendencies (*I.P. test* 146/55*T*)—Lubricating oil, like many other liquids, tends to foam when intimately mixed with air. Foaming may occur when oil from a return line drops from too high a level, when there is violent agitation by the action of gears, cranks, etc., or by high-velocity discharges, low suction heads, or leaks in suction lines of hydraulic or other systems.

Persistent foam can result in unsteady working which makes pressure control difficult and results in a loss of lubricant. Also, by bringing large oil surfaces into intimate contact with air, it may accelerate the rate of oxidation and so reduce its useful life. In a foam test, the sample is air-blown under prescribed conditions for a standard time and the volume of foam after blowing and after settling is reported.

LUBRICATING GREASES

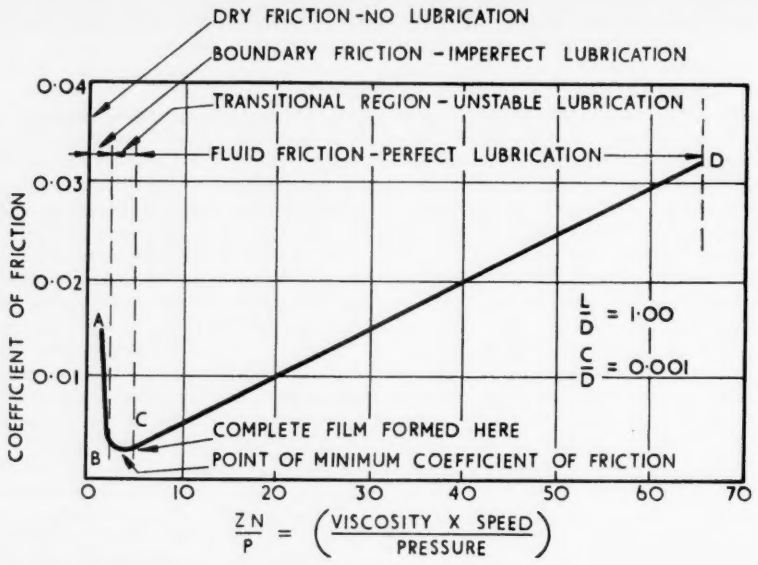
Basically, a petroleum grease is a mineral oil and a metallic soap, and is used as a lubricant when it is not practical or convenient to use oil or when the heat transferability of a lubricating oil is not needed. Greases are more serviceable than oils where bearings cannot be sealed against leakage of lubricant, ingress of dirt or water, or when they are inaccessibly placed. Within limits they make good ball- and roller-bearing lubricants because of the small quantity of lubricant required by this type of bearing.

Because of their complexity they are not so uniform as lubricating oils, nor are they as resistant to oxidation. Their lubricating value depends largely on the mineral oil used in their formulation, those made from light oils being generally used for high speeds, light load and low temperatures, and those from high viscosity oils, for low speeds and heavy loads at high temperatures.

Greases are usually classified according to the type of soap base they contain, for these soaps have a major influence on their consistency, texture, melting point, solubility in water, and heat resistance.

Calcium soap-base greases, generally referred to as ' cup greases,' have a smooth buttery texture, low internal cohesion, and poor stability at high temperatures. They are well suited for plain or ball- and roller-bearings operating at moderate speeds and temperatures, particularly in the presence of water, but normal grades, if held for any length of time at temperatures above 180° F, may lose their stabilizing water and separate.

Sodium-base greases have a relatively high melting point, a tougher texture and are generally more adhesive at higher temperatures but being slightly soluble in water they are more liable to wash out than are the calcium-base types. Their ability to absorb small amounts of moisture imparts a certain degree of rust prevention when they are used in damp



L = bearing length
D = bearing diameter
C = bearing-journal clearance

Fig. 1—Characteristic $\mu = ZN/P$ curve

atmospheres. They are capable of withstanding mechanical agitation and can be used for plain or ball- and roller-bearings operating at moderate to high temperatures and speeds.

Lithium-base greases resist the washing action of water, have a fairly high melting point and good low-temperature torque and pumpability characteristics. They combine several desirable properties not found together in the more commonly used types, and because of this versatility, have been referred to as " multi-purpose " greases.

Mixed-base greases containing two different types of soap are formulated with a view to combining in one product the advantages of both. Typical of this class are the familiar lime/soda greases. Many of these have the buttery texture of the calcium greases; they are practically water free and will resist leaching by water, and have melting points approaching those of sodium-base greases. Many of the better-known ball- and roller-bearing greases belong to this category.

Greases made with special soaps such as aluminium, strontium, and barium, and latterly the non-soap base bentones have been developed to meet specific operating conditions but in the main the diverse requirements of iron and steelworks can be adequately met by greases from the four main groups.

Table I shows the information usually given in a typical grease specification.

The bleeding, leaching, and oxidation stability characteristics, together with the apparent viscosity, if properly interpreted, can also materially assist the user in assessing the potentialities of the many products from which he must often choose.

FACTORS INFLUENCING THE PERFORMANCE OF LUBRICANTS

The overall performance of a lubricant will be governed by the sum total of all its properties but the significance of any specific characteristic will not be the same in all circumstances.

Viscosity

The primary aim of bearing designers and lubrication engineers should be to achieve hydrodynamic lubrication. Where there is a possibility of fluid-film breakdown (thin film and boundary conditions) the lubricating oil must possess anti-weld properties which are imparted by suitable film-strength additives. Under hydrodynamic conditions, viscosity is the physical characteristic requiring most attention. The selection of viscosity depends upon the combined effect of load, speed, and temperature. The effect of load and speed is illustrated by the ZN/P relationship (Fig. 1) which shows that, with increasing load or decreasing speed, film thickness can only be maintained by a corresponding increase in viscosity. Because of the reduction of viscosity with increasing temperature it is equally important to relate viscosity to operating temperatures. Each of these influences will interact with one another in such a way that

Table I
TYPICAL GREASE SPECIFICATION

Texture	**Described as buttery, smooth, fibrous, stringy**
Soap	**Type: calcium, sodium, lithium, lime/soda, lime/lead, etc.**
Oil	**Content expressed as wt-%, viscosity at 100°F**
Moisture	**Wt-% (I.P. test 74/55)**
Ash	**Wt-% (I.P. test 5/42)**
Consistency	**Penetration number, worked or unworked (I.P. test 50/55)**
Drop Point	**Reported in °F (I.P. test 31/55)**
Corrosion	**Copper strip; negative, discoloured, etched, pitted (I.P. test 112/48T)**

with any particular combination of load, speed, and operating temperature, there will be an optimum viscosity consistent with minimum power loss and maximum bearing protection.

Viscosity Index

Since it is seldom possible to maintain operating conditions at a constant value, the rate of change of viscosity with temperature is important. The energy consumed in overcoming viscous resistance is converted into heat within the oil, raising its temperature and by so doing lowering its viscosity, equilibrium only being reached when the heat generation equals the dissipation from the system. Changes in ambient temperature affect not only the viscosity of the oil as fed but also the dissipation characteristics of the system. Since changes in speed will affect the heat generated within the oil itself and changes in ambient temperature will affect the ability of the part being lubricated to dissipate it, the final viscosity will be maintained nearer the desired value when oils with high viscosity index are chosen.

Flash Point

It is not usual to operate lubricating oils at temperatures approaching their flash points. Generally, where high operating temperatures are involved or where there is a danger of oil contact with hot surfaces, a high flash point is desirable.

Pour Point

The pour point of a lubricating oil becomes important where it is subject to low ambient temperatures particularly where a gravity-type feed is employed.

Method of Application

Two identical machines performing the same duty, one lubricated on the all-loss principle and one arranged for oil circulation, will differ basically only in the manner by which the lubricant is applied, but as a result the oxidation stability of the lubricant will be of little account in the first case and of considerable importance in the second. Similarly, the foaming tendencies of an oil will only be significant under conditions where the features of the lubricating system are such that foaming is a possibility (e.g. oil circulation, bath).

Again, there are applications where emulsification cannot be tolerated (e.g. pinion and roll-neck bearing oil circulation systems) and others where it is eminently desirable (e.g. wet steam cylinder lubrication).

This shift of emphasis applies to practically every characteristic and must be considered if adequate lubrication is to be attained at the lowest cost.

CLASSIFICATION OF LUBRICANTS[5]

While the lubricant-supplier's survey will contribute towards rationalizing lubricants within a works, it will not in itself automatically organize an inventory control system which can be relied on as an inflexible method of controlling the disposition of lubricants from machine to machine, and yet be resistant to unnecessary additions or alterations due to external recommendations. Even under such widely varying conditions as exist in the iron and steel industry, it is justifiable to limit the number of lubricants to a minimum and yet maintain a sufficient variety of types to permit proper lubrication of plant in use.

Lubricant control can only be attained by a logical and ordered process. The primary stage in the process is the classification of lubricants according to their general usage. This sets out to achieve a minimum number of groups within which all applications may be accommodated. The description of the applications embodied by the group must therefore be of a general nature yet have definite boundaries to avoid confusion in identifying products within the classified group. This procedure has been simplified for the user by the adoption of a similar form of rationalization by the major lubricant suppliers, to facilitate world-wide branding of products.

The description of use should be concise yet sufficiently explicit and each classified group should be identified by a brief title. Table II shows a tabulated classified list of lubricants which, it is suggested, will adequately cover the range of requirements within iron and steelworks.

Once such a table is established, it is necessary (*a*) to test the completeness of the classification, and (*b*) to list alongside each group those products which are known to comply with each requirement. This implies a true knowledge of lubricants but it is also the point at which the lubricant supplier's survey makes a valuable contribution. Such surveys tacitly fulfil the foregoing requirements by furnishing a comprehensive library of machines, working parts, and recommended lubricants. It is to the supplier's advantage to compile the survey in such a way as to keep the number of lubricants involved to a minimum. In a complementary way he is satisfying the user's requirements. Nevertheless the supplier may still be influenced by machine-builders' recommendations which the supplier himself has fostered. To keep faith with the machine builder he will therefore put forward in his survey those grades which are appropriate to and which may indeed actually constitute, the machine-builder's recommendations.

Whatever importance is attached to the classification of lubricants in defined groups, it is equally important to rationalize products within groups and between groups. This involves two forms of compromise. For example, two enclosed reduction gear units subject to similar duties but reasonably varying speeds should be lubricated by oils of the same type but corresponding different viscosities. Under these circumstances, compromise implies one of two things: (*a*) to select a gear oil with a viscosity intermediate between the two oils in service and use that grade in both units or (*b*) to put the oil with the higher viscosity in both units. In case (*b*), the greater fluid friction in the higher speed unit is preferable to possible metallic contact and wear which results from putting a lower viscosity oil in the lower speed unit. This general procedure may be termed ' compromise by application.' It has been highlighted more particularly in selecting the viscosity suitable for the the lubrication of film-lubricated bearings on continuous mills where there is a wide difference between the speed of the first and last stands. Compromise by application is somewhat simplified with present-day lubricating oils where synthetic load-carrying capacity can be imparted to the oil by additives without change in viscosity.

Again, a large quantity of 'additive circulating' oil may be used for its rightful application (say a turbine system) and a relatively small quantity of a lower quality 'engine' oil used for oil-ring lubricated bearings. The former will more than adequately withstand the operating conditions of the oil-ring bearing. The procedure is therefore to dispense with the 'engine' quality and increase the requirement for the 'additive circulating' type by that amount required for the oil-ring bearing application. This may be termed 'compromise according to consumption,' and the extent to which it is practised will depend on how much value is placed on rationalization to offset the additional cost of the higher quality product, though it does not necessarily follow that higher quality means higher costs. Each case must be considered and judged accordingly.

It is increasingly apparent that the users of lubricants wish to have some say in the preparation of those lubricants. Compared to the supplier, the user of a lubricant feels that he has a greater knowledge of the plant he operates and of what he expects from the lubricants he purchases. On the other hand, the supplier has a greater knowledge of the characteristics of his products and of how they may be modified to meet a particular demand. Consequently the matter of specifying lubricants is a two-party affair. If the user intends to draw up a specification of a lubricant, he must be prepared to lay down physical, chemical, and performance requirements so that they can be assessed by standardized and reliable methods, and he must be prepared to accept the responsibility should he omit some necessary characteristic in his specification or find that his specified performance limits fall short of direct practical interpretation.

On the other hand, it is possible for the user to identify his requirements more closely without in any way relieving the supplier of his obligations. This is the method adopted by certain sections of the iron and steel industry, and it consists of supplementing

Table II

CLASSIFICATION OF INDUSTRIAL LUBRICANTS AND ALLIED PRODUCTS

Group Classification	Description of Use	Group Classification	Description of Use
A. LUBRICATING OILS			
Cylinder oils	Dark oils, suitable for steam cylinder lubrication	Additive circulating oils	Highly refined oils suitable for circulating and turbine systems and incorporating one or more additives to enhance stability and metal protection
Engine oils	Once-through lubricating oils such as used for hand oiling		
Gear oils	Oils suitable for enclosed gears lubricated by splash or spray	I.C.E. oils	A range of I.C.E. crankcase oils composed of regular, premium and heavy-duty types
Non-additive circulating oils	Lubricating oils sufficiently refined for circulating systems but without additives	Hydraulic oils	Specially selected additive type oils suitable for hydraulic systems
B. PROCESS AND ALLIED OILS			
Electrical oils	For electrical transformers and switchgear	Rust preventive oils	Oils and compounds suitable for corrosion protection
Soluble cutting oils	For machining operations where a soluble type oil is required and for certain water hydraulic systems	Heat treatment oils	Oils used as quenching media for heat-treatment of steels
Straight cutting oils	For machining operations where a straight oil is required	Roll oils	Selected oils suitable as a roll lubricant for cold rolling ferrous materials
C. LUBRICATING GREASES			
Cup greases	'Common' greases suitable for plain bearings where stability is not of prime importance	Roll neck greases	Range of greases with characteristics suitable for application to grease-lubricated roll neck bearings
Ball and roller bearing greases	Stable greases suitable for ball and roller bearings where operating life may be extensive	Skid greases	Low quality greases for use on skid rails, accumulator slides, etc.
High melting point greases	High quality greases capable of operating continuously at temperatures up to 300° F	Graphited greases	For special applications where graphite is required as a constituent of the grease
Axle greases	Suitable for railway wagon axle boxes		
D. INTERMEDIATE PRODUCTS			
Definition High viscosity residual type oils with or without additives, possessing special adhesive properties and having physical characteristics intermediate between those of lubricating oils and greases. In general, the main constituent of these products is bitumen.		General Description of Use For application to slow moving, heavily loaded gears, wire ropes, slides and certain roll necks where, subject to severe conditions of water, load and temperature, oils and greases are not considered suitable.	

the classified table by a ' control ' specification which restricts the values of a limited number of physical characteristics.

The authors' own company has passed through two phases in developing control specifications. In the original phase, all lubricants were classified into groups, and within groups a sufficient range was incorporated to accommodate all the known major requirements. To each of these sub-group products rather loose control specifications were assigned. These included the following characteristics:

Oils

(i) Maximum specific gravity
(ii) Minimum closed flash point
(iii) Maximum pour point
(iv) Viscosity range both in Redwood seconds and centistoke units, a maximum value being given at the lower temperatures and a minimum at the higher temperatures
(v) Certain other characteristics limited to particular groups.

Greases

(i) Type of soap base
(ii) Acceptable range of ' worked ' consistency
(iii) Minimum drop point.

It was found necessary to develop a third group of lubricants possessing physical characteristics between oils and greases. The members of this group (*see* Table II) were termed ' intermediate products ' and defined as follows: " High viscosity residual type oils with or without additives, possessing special adhesive properties and having physical characteristics intermediate between those of lubricating oils and greases. In general, the main constituent of these products is bitumen."

These products were specified simply by the viscosity in Redwood No. 1 seconds or No. 2 seconds (for the heavier products) at 200° F, and in centistoke units at 210° F.

Experience in using the foregoing system indicated three main faults:

1. It was not possible to accommodate changes in product requirements without alterations to or complete revision of, the specifications. This would have meant new sub-group product titles to maintain as many ' classified ' grades as possible. The result of this was that although some ' unclassified ' products could be tolerated, their number grew rapidly.

2. The control specifications for the lubricating oils were originally drawn up to embrace a limited range of products complying, so far as application was concerned, with the sub-group requirements. The inevitable looseness of the specification meant that two products, one complying with the top end of the specification scale and one complying with the bottom end of the same scale, could be acceptable for the same apparent requirement.

It was also possible for products to satisfy the specification applying to more than one successive sub-group. This is a pitfall common to many machine-builders' recommendations, where overlapping of physical characteristics between succeeding recommen-

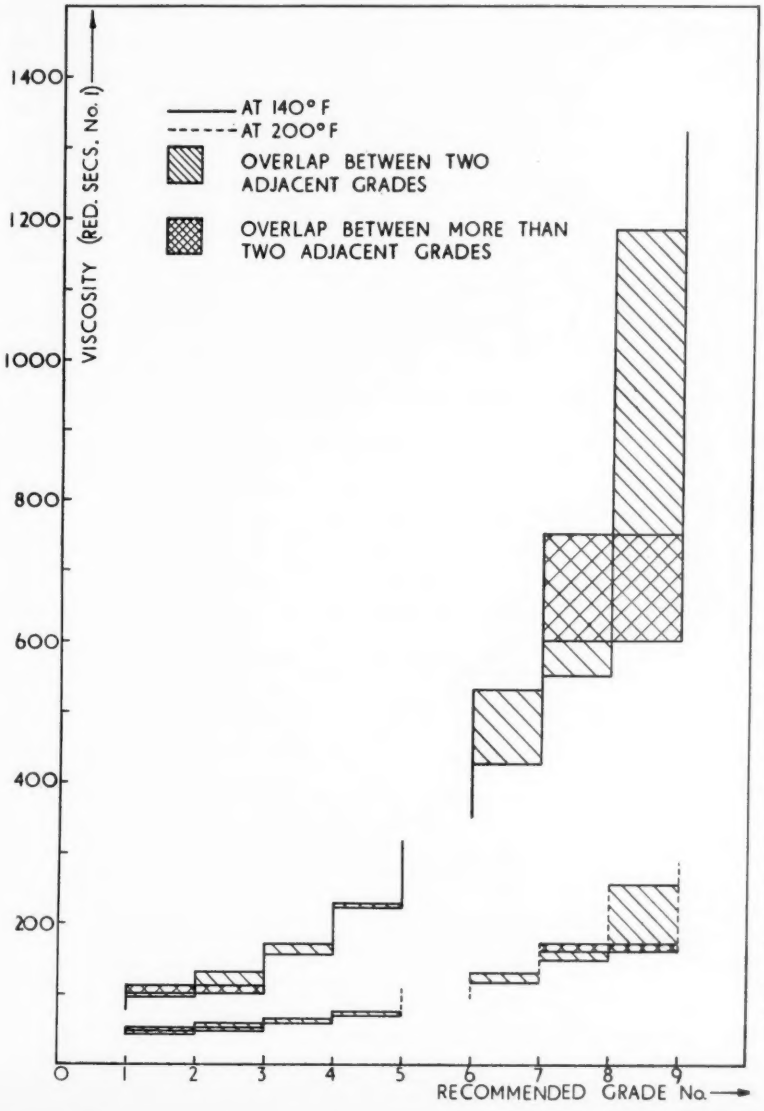


Fig. 2—Ranges of viscosity spanned by typical manufacturer's recommended grades showing overlap

dations is not uncommon. For example, Fig. 2 shows the ranges of viscosity at two temperatures (140° F and 200° F) spanned by the various grades incorporated in each of a successive table of a typical manufacturer's recommendations. The single hatched areas show overlap between two adjacent grades and double hatched areas show overlap between more than two adjacent grades.

3. No satisfactory method could be evolved of identifying products, particularly due to fault (2).

This applied equally to the lubricating greases where no standard system was used to rate consistency, the ranges of consistency being taken (more or less at random) to cover known and accepted products.

It had long been felt the apparent failure of BSS 210: 1939 (Lubricating Oils) to achieve recognition similar, say, to the S.A.E. ratings, would merit some form of universally acceptable 'viscosity classification.' Although a committee of the American Society for Testing Materials has been working on this for some time, the authors' own company decided to develop a classification suited to their own requirements. This was done and now forms the basis of their lubricating oil specifications. The classified groups were reconstructed, superfluous information was eliminated from the specifications, requirements particular to a group were introduced, unclassified products were removed, and a more realistic method of identifying products was developed.

In like manner, the N.L.G.I. ratings were embodied in the lubricating grease specifications. The advantages of these changes may be summarized as follows:

1. Overall specifications are simplified as all irrelevant characteristics are omitted. Viscosity at one temperature (100° F) controlled by a specified minimum viscosity index is the only main factor involved in the specification. Other characteristics are either implied by the description of use, or, in special cases, have limiting values placed on them.

2. The Viscosity Classification Table is constructed to satisfy all present and future requirements. All grades can thus be classified and there is complete freedom of choice within the very ample range covered by the table. It might well be argued that although there is no overlap in the table, the range of viscosity covered by any single member of the table is severely restricted, and that such a considerable freedom of choice could lead to an increase in the overall number of products used. This could be true if not intelligently applied, but in practice it has been shown that by highlighting ranges of products which vary little in viscosity, considerable reductions can be achieved in the number of products involved.

The range of viscosity covered by any single member of the table was actually designed to embrace the limits given by the change in viscosity due to a change of temperature of $\pm$ 5° F with a standardized *V.I.* of 75, i.e. the difference in viscosities at 95° F and 105° F for a particular nominal viscosity at 100° F, when the *V.I.* is 75.

3. The viscosity classification (for the lubricating oils) and the N.L.G.I. rating (for the lubricating greases) has enabled a simple but flexible method of identifying products to be devised.

Typical specifications and the method of coding are shown in Table III.

The success of this programme of classifying lubricants is illustrated by experience over a period of six years during which the programme developed, when there was a 25% financial saving on the overall cost of lubricants. During the same period the number of different grades of lubricant was reduced by 35%.

IDENTIFICATION OF LUBRICANTS

The system of specifying lubricants, outlined in the foregoing, facilitates the identification of the various products by a simple code combining digits and letters. There is a wide variety of coding methods used, from simple digits to combinations coding the type of product, its origin (i.e. supplier), types of additives, and one or more physical characteristics. The choice of code varies with individual taste but it should logically be designed to fit in with an ordering and accounting scheme.

Various attempts have been made to widen the scope of identification by the use of colour code systems. So far as the authors are aware, these have not been attempted in the iron and steel industry in this country. However, at Mannesmann Huettenwerke at Huckingen, Germany, an interesting system has been introduced into a steelworks apparently with success. This operates as follows: The normal requirements of lubricants for each department in the works were originally assessed and drawn up on a plan. The various departments can normally and automatically draw from the stores department only that quantity of lubricant assigned to them on the plan. In cases of increased production or for other reasons where additional lubricants are required, these can only be drawn against the authorization of the engineer in charge of the programme.

A colour code system has been evolved to improve the control in the distribution and application of lubricants. Oils are indicated by coloured horizontal lines and greases by coloured vertical lines. This system is indicated in Fig. 3, and copies of the colour key are issued in card form to all personnel concerned with lubrication, and in the form of large enamelled plates for display in each department and the main stores.

The quantities of lubricants in stock are assessed on the 20th of each month by a lubrication inspector. By balancing these with planned requirements for the ensuing period, it is possible to place the necessary orders for fresh supplies through the purchasing department. The lubrication inspector is also responsible for checking deliveries from the suppliers, issues from the main stores, and for sampling each batch of lubricant. The samples are checked in the laboratory and only then can the batch be released for issue on the plant.

Although lubricating oils are received in barrels, the oil is tested and then transferred to storage tanks in the main store from which issues are made through metering gauges. The colour code is used throughout: on the barrel, on the pipelines to the storage tanks, on the tanks themselves, on the dispensing cupboards (at the issuing section of the store) and on the containers into which issues are made. The main store

No	COLOUR	OILS
1		DISTILLATE
2		REFINED
3		CYLINDER OIL
4		LIGHT GEAR OIL
5		COMPRESSOR GEAR OIL
6		BATH OIL
7		GEAR DRESSING
8		TURBINE OIL
9		TRANSFORMER OIL
10		FILTER OIL
11		ELDRO OIL
12		MOTOR OIL
13		WASH OIL
14		DRILL OIL
No	**COLOUR**	**GREASES**
1		MACHINE GREASE
2		CRANE GREASE
3		ROLLER BEARING GREASE
4		SPECIAL GREASE
5		ROLL JOURNAL GREASE
6		GEAR GREASE WIK 600
7		COUPLING GREASE
8		SOFT GREASES

Fig. 3—Colour code system as used at Mannesman Huettenwerke

Table III

TYPICAL SPECIFICATIONS AND METHODS OF CODING PRODUCTS

A. LUBRICATING OILS

Group Code	Group Classification	Description of Use	Specification: Viscosity Classification No.	Specification: Other Characteristics	Remarks
3/16	Hydraulic oil	Specially selected additive-type oils suitable for oil hydraulic systems	4 6 8 10 ..	(i) Min. *V.I.* to be 75 (ii) Rust and oxidation inhibited (iii) Max. pour point 15° F	

Viscosity Classification Numbers

Class	Viscosity cS at 100° F Nom.	Min.	Max.	Red Secs. No. 1 at 100° F* Nom.	Min.	Max.	'Equivalent' S.A.E. rating for I.C.E. oils only: Crankcase	Transmission
1	4·0	3·0	5·1	36	33	39		
2	6·3	5·1	7·6	41	39	45		
3	9·0	7·6	10·7	49	45	53		
4	12·5	10·7	14·5	60	53	66		
5	16·5	14·5	19·0	73	66	82		
6	21·5	19·0	24·5	91	82	103		
7	27·5	24·5	31·0	114	103	128		
8	34·5	31·0	39·0	142	128	160		
9	43·5	39·0	48·5	178	160	198		
10	61·0	48·5	74·5	247	198	303	..	..
11	92·5	74·5	112·5	376	303	458	20/20 W	..
12	140	112·5	170	570	458	692	30	..
13	205	170	250	835	692	1018	40	90
14	305	250	370	1242	1018	1505	50	..
15	455	370	550	1852	1505	2239	..	..
16	670	550	800	2779	2239	3258	..	140
17	975	800	1170	3972	3258	4680	..	..
18	1430	1170	1720	5720	4680	6880	..	..

* Equivalent Red. Secs. No. 1 given for information only

Method of Coding

The appropriate viscosity classification number is used to identify the product thus:

3	16	6
Oil	Hydraulic oil	Appropriate viscosity at 100° F

The use of code letters, to identify particular types of products within a classified group, operates thus:

3	10	18	(C)
Oil	Cylinder oil	Appropriate Viscosity at 100° F	Compounded

Other code letters include E.P. = extreme pressure; H.D. = heavy duty, R = regular, P = premium (motor oils), T = transmission (gear oil)

B. LUBRICATING GREASES

Group Code No.	Group Classification	Description of Use	Specification: Soap Base	Specification: Consistency (N.L.G.I. No.)	Specification: Drop Point (° F Min.)	Remarks
4/10	Cup grease	A range of 'common' greases for plain bearings operating under wet or dry conditions where temperatures do not continuously exceed 110° F	Lime	1 3 4	190	

N.L.G.I. No.	A.S.T.M. 'worked' penetration
0	355–385
1	310–340
2	265–295
3	220–250
4	175–205
5	130–160
6	85–115

Method of Coding

The appropriate N.L.G.I. number is used to identify the product thus:

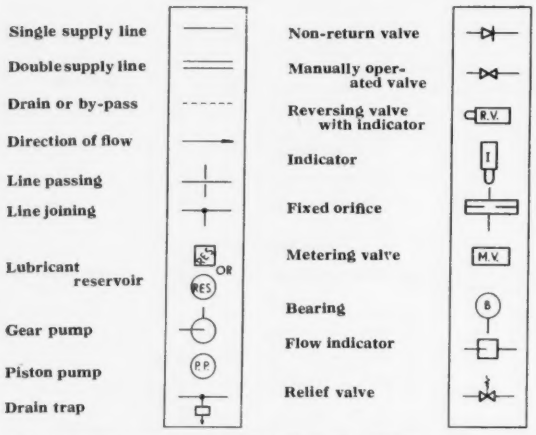
4	10	1
Grease	Cup grease	No. 1 N.L.G.I. consistency

C. INTERMEDIATE PRODUCTS (*See* Table II for description of use)

Product Code No.	Product Classification	Specification (Viscosity): Red. Secs. No. 1 at 200° F	cS at 210° F	Red. Secs. No. 2 at 200° F
*5/11/1	No. 1 Product	270/320	65/77	..
*5/16/1	No. 6 Product	..	564/780	235/325

* Here 5 = intermediate product

Table IV
GRAPHICAL SYMBOLS USED FOR LUBRICATING SYSTEM DIAGRAMS



These symbols comply with BSS 1553: Part I: 1949 where possible.

will refuse to fill containers with oil other than that which corresponds with their markings.

The various lubricating pump containers on the plant are similarly marked but as yet individual lubrication points on separate machines are not.

Lubricants are issued from the main store on the 6th, 16th, and 26th of the month, each department having a sub-store capable of carrying 10 days' supply. These sub-stores are open only between 9 and 10 a.m. daily. This system considerably reduces time wasted by personnel on daily visits to the main stores for small quantities of lubricants.

Consumption records are maintained and it is claimed that the lubrication programme has resulted in a large reduction in consumption of lubricants. With an increase in production of 39·8% from 1939 to 1952, specific lubricant consumption has decreased from 394 g/ton (13·8 oz/ton) in 1939 to 268 g/ton (10·6 oz/ton) in 1952, a corresponding drop of 32%.

Experience of the last ten years in iron and steelworks in the U.K. has indicated that control and careful selection of lubricants can produce rewarding dividends, themselves capable of multiplication by equal attention to how those lubricants are applied.

Part II—THE APPLICATION OF LUBRICANTS

During the post-war years there has been a remarkable advance in the technique of applying lubricants. This has not been confined solely to the iron and steel industry but has been reflected by some of the major development programmes in that industry. It is not claimed that this progress was engendered as a result of the activities of lubrication engineers in industry, for it was more of an inevitable development. Indeed, this progress added argument to the appointment of specialist engineers, although the parallel interest in fitting up-to-date lubrication systems to existing or old plant can be attributed to the work of industrial lubrication engineers.

Whilst many of the heavy engineering manufacturers (particularly those building rolling-mill equipment) are fully acquainted with lubrication matters, many others appear to ignore this factor in design. In highly competitive fields there may be some excuse for this, where a willingness to incorporate modern lubricating equipment is not shared by the willingness of the customer to pay that extra 'insurance.' Frequently however, little thought is given to basic lubrication in the design of plant, and it is often left to the lubrication engineer to put in those final details, sometimes even before plant can be commissioned. It is not only a question of fitting up-to-date lubricating equipment, even assuming bearings have been designed to accommodate such equipment, but it must also be ensured that the correct type of equipment has been selected.

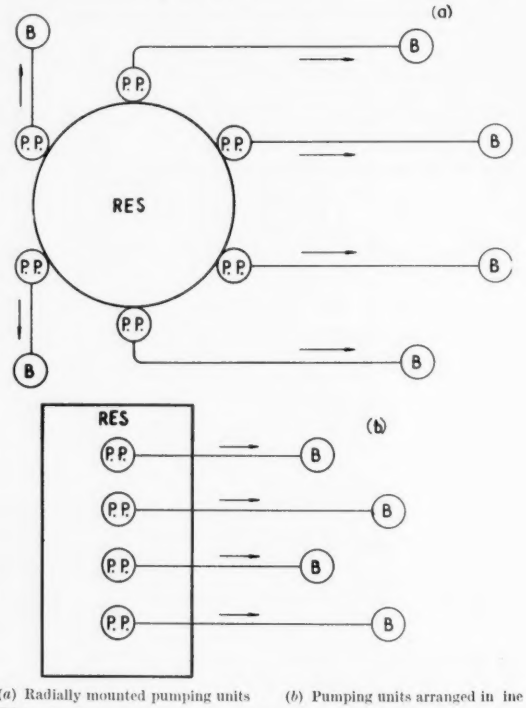
GENERAL TYPES OF LUBRICATION SYSTEMS[6]

Methods of applying lubricants can be divided generally into non-centralized and centralized. The non-centralized types (which embody such methods as grease nipple, stauffer cup, oil can, oil bottle, etc.) can be dismissed as being irrelevant to this section.

The centralized systems can be classified as:

(i) Manual
(ii) Fully and semi-automatic
  (*a*) Non-circulating
  (*b*) Circulating

Centralized systems are those where a number of bearing points using the same lubricant are linked to a pump or pumps, either directly or through proportioning valves, so that the operation of the pump or pumps permits simultaneous or sequential feeding to all connected bearing points.



(*a*) Radially mounted pumping units (*b*) Pumping units arranged in line

Fig. 4—Systems where metering is effected by pump only

The manually operated systems are almost completely of the non-circulating type, the exceptions to this being strictly limited. Their selection, as opposed to the fully or semi-automatic systems, depends primarily on the frequency of application of lubricant, and for this reason they are favoured, for example, for lubricating ' groups ' of ball- or roller-bearings.

Fully automatic systems are those whose pumps are operated quite independently of manual means. Such pumps will be driven by an electric motor, time controlled or interlocked with the motor of the machine being lubricated, or by hydraulic or air power, or they will be actuated by some moving part of the machine being lubricated. Semi-automatic systems are those actuated by the manual operation of an electric starter or a valve but which stop automatically when a cycle or series of cycles has been completed.

The general principles underlying the operating features of manually operated centralized systems apply equally to the automatic types where in many cases the systems are identical, apart from the method of actuating the pump. For this reason, we may discuss these principles generally as applying to both classes of system.

BASIC FEATURES OF LUBRICATION SYSTEMS*

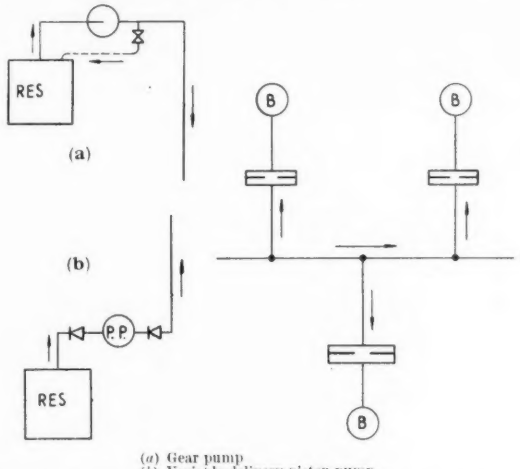
Non-circulating systems

Centralized manual and automatic non-circulating systems can be divided into three types:

1. *Metering effected by pump only*

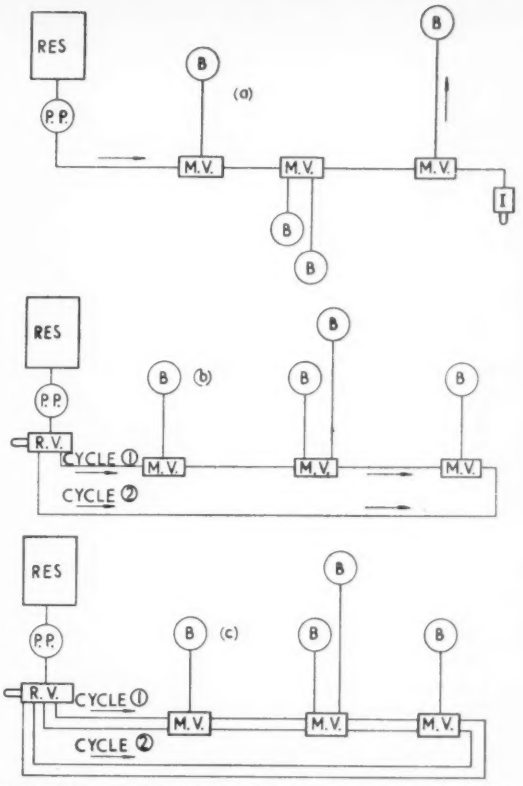
In such systems metering of lubricant is effected by individual pumping units arranged radially or in line with respect to their actuating mechanism in the main ' pump ' or reservoir body. The output from each pumping unit is adjusted by altering the effective stroke of the piston incorporated in the unit. This type of system is shown in Fig. 4, the ' radial ' unit operating satisfactorily with either oil or grease and the 'in-line' unit operating satisfactorily with oil only.

* A table of graphical symbols used for the lubrication system diagrams is shown in Table IV.



(*a*) Gear pump
(*b*) Variable-delivery piston pump

Fig. 5—Systems where metering is effected by fixed orifices



(*a*) Single line (dead end) (*b*) Single line (return to pump) (*c*) Double line

Fig. 6—Single- and double-line series systems

2. *Metering effected by fixed orifices*

In this type of system, the pump passes into the main line a quantity of lubricant which is apportioned to each bearing by fixed orifice metering valves. The supply to any one bearing can only be adjusted by altering the size of its corresponding orifice. The supply to all bearings can, however, be adjusted collectively by the setting of a by-pass valve in the main line. This system, which is suitable for oil lubrication only, is shown in Fig. 5. The same principles are also used in many of the large oil circulating systems.

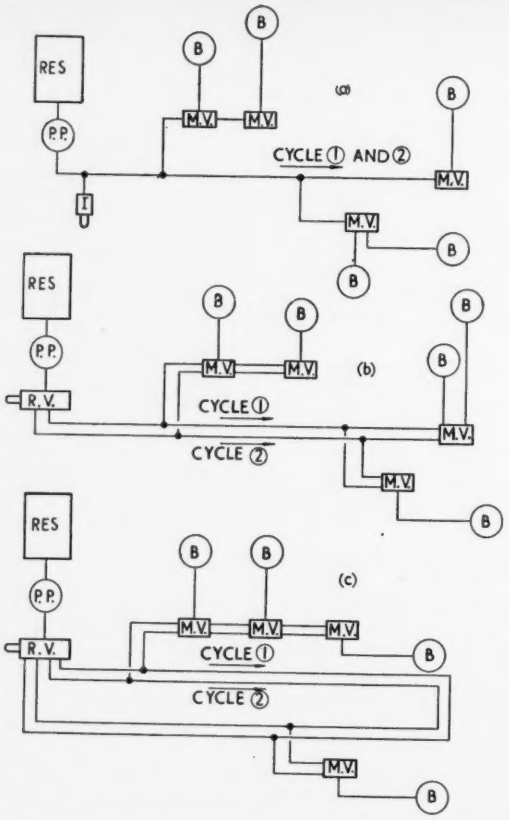
3. *Metering effected by individual metering valves*

In this type of system, a pump delivers lubricant until a series of metering valves has passed a preset quantity of lubricant to each bearing. Such systems are suitable for dispensing either oil or grease and can be sub-divided as follows:

(i) Single- or double-line systems (*see* Fig. 6) operated on the series or progressive principle. The single-line versions may be of the ' dead-end ' or ' return-to-pump ' types, whereas the double-line versions are all of the ' return-to-pump ' type.

The principle of the series or progressive systems of lubrication is that each metering valve will not permit lubricant to flow to the valve, adjacent and ahead in sequence, until it has operated itself.

(ii) Single- or double-line systems operating on the parallel principle. In parallel systems, the



(*a*) Single line (*b*) Double line (*c*) Double line (return to pump)

Fig. 7—Single- and double-line parallel systems

feed from any one metering valve to its associated bearings is not dependent on the operation of its preceding valve or any other. As soon as the pressure in the main line overcomes the bearing back pressure on any metering valve discharge, then the valve will operate. Therefore, it is usual to charge the system to a known pressure to ensure that all valves operate. These systems may be: (*a*) single line, in which the valves adjust themselves automatically on relieving the pressure (Fig. 7*a*); (*b*) double line in which the valves are re-actuated by pumping lubricant down a separate line (Fig. 7*b*), double line, with ' return to pump ' (Fig. 7*c*).

Branched systems (Fig. 8)

Here, the lubricant passes from the pump to a master dividing block and thence to metering valves which re-adjust themselves internally during consecutive cycles. Owing to their self-cycling design, no lubricant reversing mechanism is required.

Circulating Systems

Circulating systems suitable for oil lubrication only are of two types: (*a*) gravity operated; (*b*) pressure operated.

In gravity-operated systems, although pressure pumps play an mportant role, supply of lubricant to bearing surfaces is by gravity. A typical example is shown in Fig. 9 where the system consists of a main supply tank, a pump, and a 'gravity' tank intermediate

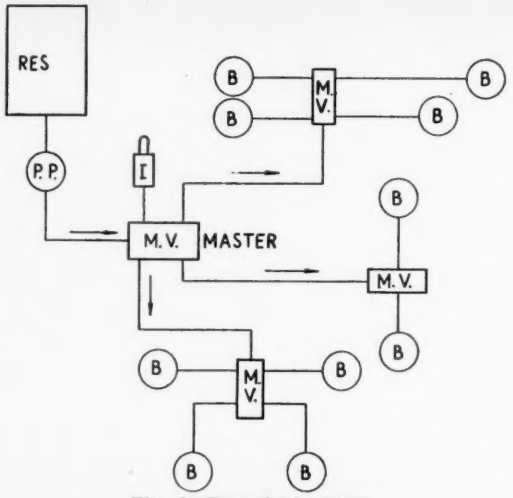


Fig. 8—Branched system

between the pump and the points to be lubricated. Operation is controlled by a float switch, which in the lower position starts the pump supplying oil to the gravity tank. When the float reaches its upper position the pump is stopped automatically. Oil is fed from the gravity tank to the bearings, each of which is fitted with a sight feed indicator and flow regulator. In other versions the pressure pump is running continuously, surplus oil being returned to the main supply tank through an overflow connection fitted to the gravity tank. In the float-switch operated version it is a precaution to fit an overflow in case of malfunctioning of the float or switch.

The gravity-operated circulating system is limited to the pressure available from the gravity head. It has, however, the advantage of incorporating an adequate reserve supply of lubricant in the event of a breakdown of the pressure pump, warning of which should be available. For this reason, standby gravity

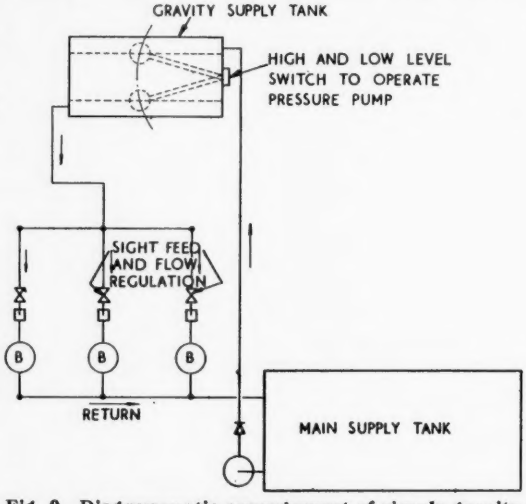


Fig. 9—Diagrammatic arrangement of simple gravity-type oil circulating system

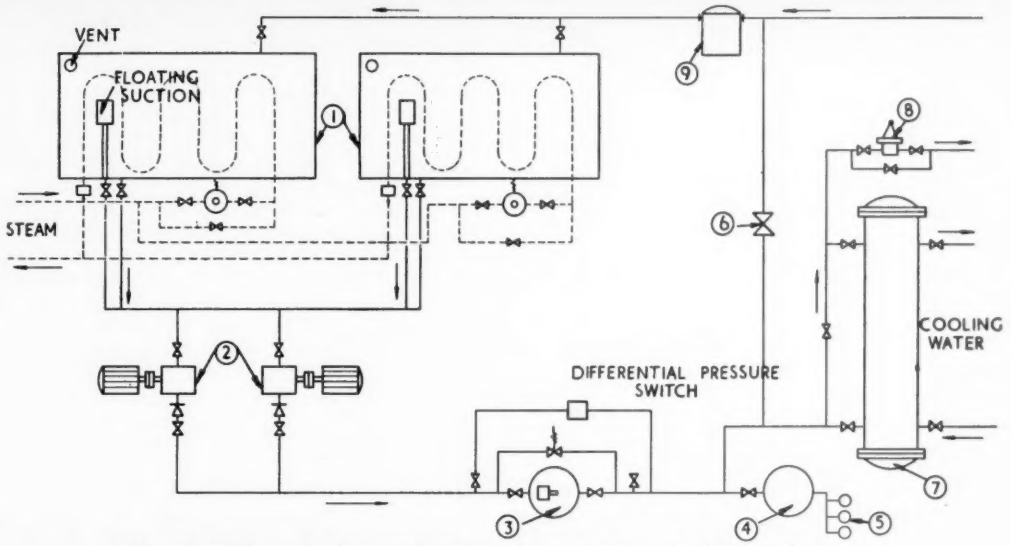


Fig. 10—Diagrammatic arrangement of pressure-type oil circulating system

type systems can be incorporated in pressure-type circulating systems.

Pressure-type circulating systems vary considerably in complexity and size, but in the iron and steel industry the main interest in this type of system is centred around rolling mill applications. A typical comprehensive arrangement of the latter is shown in Fig. 10. This consists of two tanks (*1*) one of which is in service while the other is at rest settling out contaminants or being centrifuged. Duplicate tanks are used for applications where the ingress of water to the system is a serious factor. A single tank with twin compartments is not to be recommended as a substitute for two separate tanks because of the transfer of heat from one side (the ' settling ' tank) of the dividing plate to the other (the ' service ' tank). The supply tanks are fitted with vents and some form of heating, either steam or electric, the temperature of the oil being regulated automatically. The oil-circulating pumps (*2*) are fitted in duplicate, one acting as the normal service pump and the other as the standby. An automatic self-cleaning filter (*3*) fitted in the supply line, ensures ' fine ' filtration of the oil before delivery to the bearing surfaces. It is operated by a differential pressure switch and is protected by a pressure regulated by-pass. The pressure vessel (*4*) serves several functions: (*a*) it balances fluctuations in pumping pressures, (*b*) it controls the alarm system (*5*) in the event of falling pressure which in turn will bring in the standby pump, and (*c*) it is also available (according to its capacity) as a limited emergency store of oil if there is a complete failure of the system. The system control valve (*6*) is fitted prior to the cooler (*7*) and the final pressure is regulated by valve (*8*).

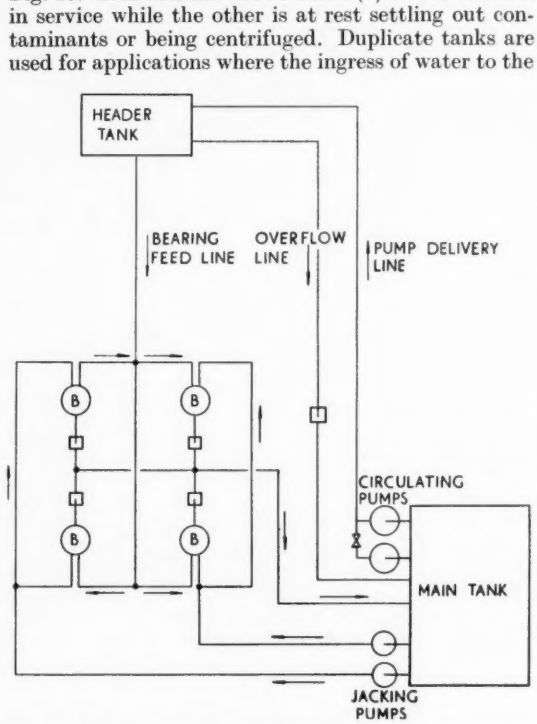


Fig. 11—Diagrammatic arrangement of primary crusher lubricating system

It is becoming common practice to incorporate magnetic filters in such systems. These are intended to remove ferrous material (generally scale) and may be in the form of a combination magnetic-mechanical filter which replaces the conventional self-cleaning filter, or in the form of magnetic filters (*9*) placed in the return lines. The positioning of the latter, which are additional to the conventional filter, has the advantage of eliminating ferrous material from the supply tank and consequently the pump suctions. They are particularly advantageous during the flushing of the system where pipe scale may be a hazard.

ROLLING MILLS

Centralized automatic lubricating systems applied to rolling mills will conform in principle to one or more of the types outlined but will differ considerably

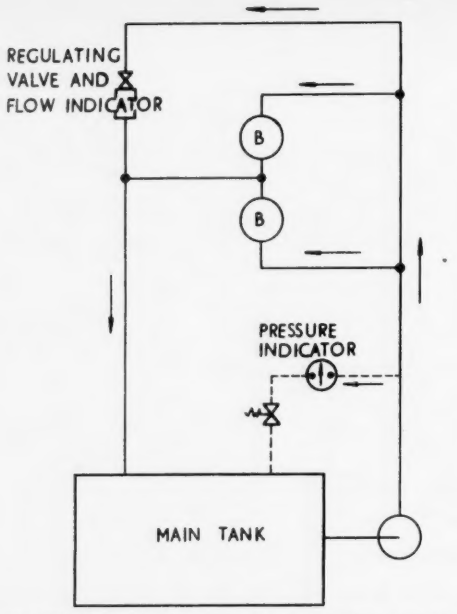


Fig. 12—Diagrammatic arrangement of secondary crusher lubricating system

in detail according to the size, layout, and final product of the mill. To describe in detail a representative number of typical installations is a task of some magnitude and reference can only be made here to an article[7] reviewing the modern approach to the subject. While much attention has been focused on the subject of rolling-mill lubrication, it should be borne in mind that other sections of the industry are equally vital.

IRONMAKING PROCESSES

It can be claimed with justification that centralized automatic lubricating systems are more essential for modern blast-furnace equipment than for rolling-mill equipment, for the former is called upon to operate at maximum capacity for long periods without the attention normally afforded by mealtime and weekend breaks. In considering the development of centralized lubricating systems in the ironmaking section of the industry, the sequence of operations has been followed as closely as possible.

Primary Crushers

The system shown diagrammatically in Fig. 11 is one supplying oil on the flood principle to the bearings of a Hadfield two-roll primary crusher, each roll being 6 ft dia. and 5 ft wide. In this system, oil from the main tank is continuously pumped to the header tank. The quantity delivered is greater than that required by the bearings and the tank is consequently on constant overflow. Should the volume of this return flow fall below a pre-determined value, a mercury switch is tilted and an electrical interlock stops the crusher motor. At the same time a flag indicator on the control panel shows that for some reason the level in the gravity tank is too low. Oil from the header tanks flows by gravity at virtually constant head to the bearings. A flow indicator of the same type as that in the overflow lines, is fitted to the outlet from each bearing, and should the oil passing through any of them fall below the required quantity then the crusher motor trips the flag on the panel, indicating on which bearing the trouble has occurred. The crusher cannot be restarted until each bearing receives its proper feed.

In addition to the main circulating pumps there is a pair of ' jacking pumps,' each connected directly to a pair of bearings. These pumps supply oil at 400 lb/in^2, sufficient partially to float the journals in the bearings. They are used for starting up, and greatly assist get-away especially when the machine has been stopped under load. The oil from them is returned by the same lines as the circulating oil and is covered by the same protection devices. In starting up, the jacking pumps are run until the plant has got away, the circulating pumps are then started and when the return flow from the header tank shows that the system is operative, the jacking pumps are stopped. Thermostatic heaters in the main and header tanks control the temperature of the oil to the bearings. A good quality straight mineral oil in the S.A.E.30 range is used in this system, and it will be noticed that although pumps are used, except for starting, the bearings are gravity fed.

Secondary Crushers

The following system, which is used for the lubrica-

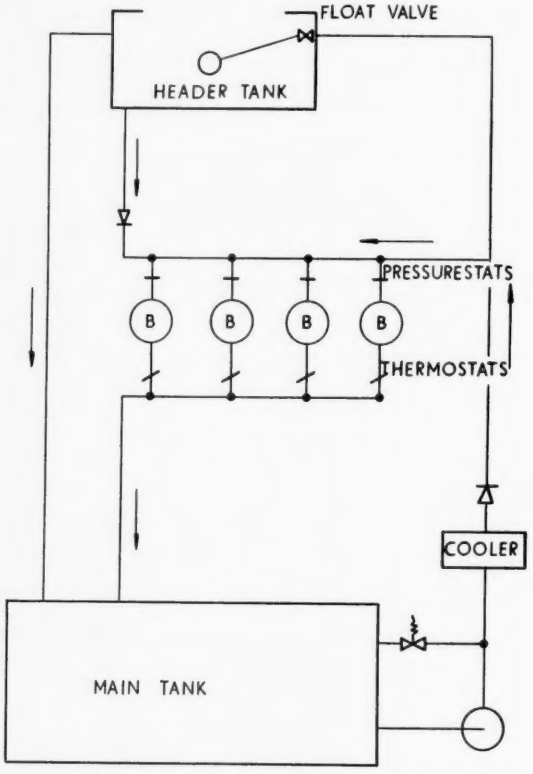


Fig. 13—Diagrammatic arrangement of sinter plant suction fan lubricating system

tion of standard 5½-ft and 7-ft cone crushers, introduces a slight variation and is shown diagrammatically in Fig. 12. The main components consist of a tank, pump, relief valve, pressure indicator, and sight feed. The tank is about 200-gal capacity and the pump is capable of delivering more than 50 gal/min, which is the maximum requirement, at pressures in excess of 20 lb/in². The primary regulation of the oil supply to the bearings is by means of the relief valve and is henceforth controlled by the indicator fitted with high–low contacts and interlocked with the crusher motor which it trips if for any reason the pressure rises above, or falls below, the set value.

The first take-off is to the step bearing and the second to the countershaft. The delivery line is then continued upward to a height of not less than 2 ft above the material feed platform, at which point it is connected through a regulating cock and sight feed to the return main. This provides a second means of flow adjustment, as closing this cock results in less oil being bled from the delivery main and more being fed to the bearing. The oil fed to the step bearing has also to lubricate the main shaft eccentric bushing and socket bearing. This part of the circuit, which rises to a considerable height inside the main shaft housing, is totally blind and this is the reason for the upward extension of the delivery line with its accompanying sight feed, in as much as, so long as oil can be seen flowing through the sight feed, the head should be sufficient to ensure it reaching the highest point within the machine. It is therefore essential that the cock regulating the bleed-off from the header line should be so constructed that it can never be completely closed. The main tank is fitted with cooling coils, and although slight difficulty has been experienced when starting up in severe weather, it has not yet been found necessary to fit heaters. The oil used in this system is a triple-inhibited, medium-heavy turbine grade.

Sinter Plant

Figure 13 is an arrangement diagram of the system used to lubricate the bearings of a 2200-h.p. motor, and the 10 ft 7 in. dia. impellers of a sinter plant suction fan which it drives. The fan bearings are 8 in. dia., 19 in. long and are both flood and ring oiled, the housings being water cooled. Originally oil from the main tank was pumped through the cooler direct to the gravity tank from which it flowed to the bearings. The head available was barely sufficient and allowed no safety margin.

The system was therefore converted to its present form by fitting the non-return valve and float valves to the pump delivery line, thereby connecting this line directly to the bearing feed main and inserting an opposing non-return valve in the gravity line connecting the header tank to bearing feed line. The system operates as follows: oil from the tank is pumped through the cooler and up the delivery line to the bearing feed line and header tank. Until this tank is full and the float valve closed, sufficient pressure will not be built up in the bearing feed line to allow the motor to be started, excess pressure being relieved by the valve at the pump. The bearings are protected by high–low pressure alarm indicators

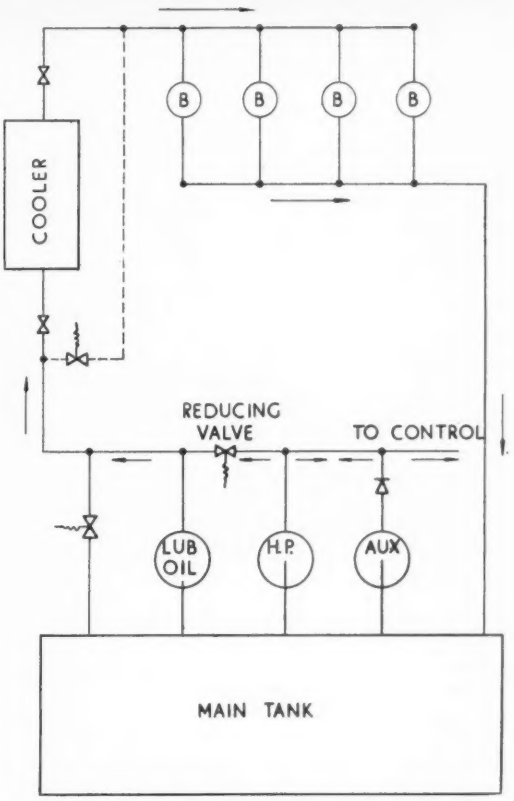


Fig. 14—Diagrammatic arrangement of turbo-blower lubricating system

fitted to the individual inlets, and high-temperature alarm indicators fitted to the wells of the bearings. Operation of any of these trips the fan driving motor, the instrument responsible for the trip being indicated on a flag panel. The overrun on these machines is considerable whether the stop is deliberate or for emergency. This is the reason for retaining the gravity tank, for if the oil pump should cease to function, due to power failure or any other cause, the non-return valve on the delivery line will close and oil will flow from the header tank into the bearing feed line, so maintaining a supply until the impellor comes to rest. This system uses the same grade of turbine oil as employed in cone crusher systems.

Turbo-blowers

The circulating oil systems of turbo-blowers usually serve the dual purpose of lubricating the machine and providing hydraulic power for operating the governing and control gear. This invariably means a two pressure system, and Figs. 14 and 15 show the arrangement of one such system serving a blower capable of delivering 75,000 ft³ of air at 30 lb/in², when running at a speed of about 2800 rev/min. The low and high pressure pumps are commonly housed and driven by a worm and wheel from the turbine rotor shaft, the surplus from the high-pressure pump being bled through a reducing valve to the low pressure side. A steam-driven auxiliary pump delivers directly into the

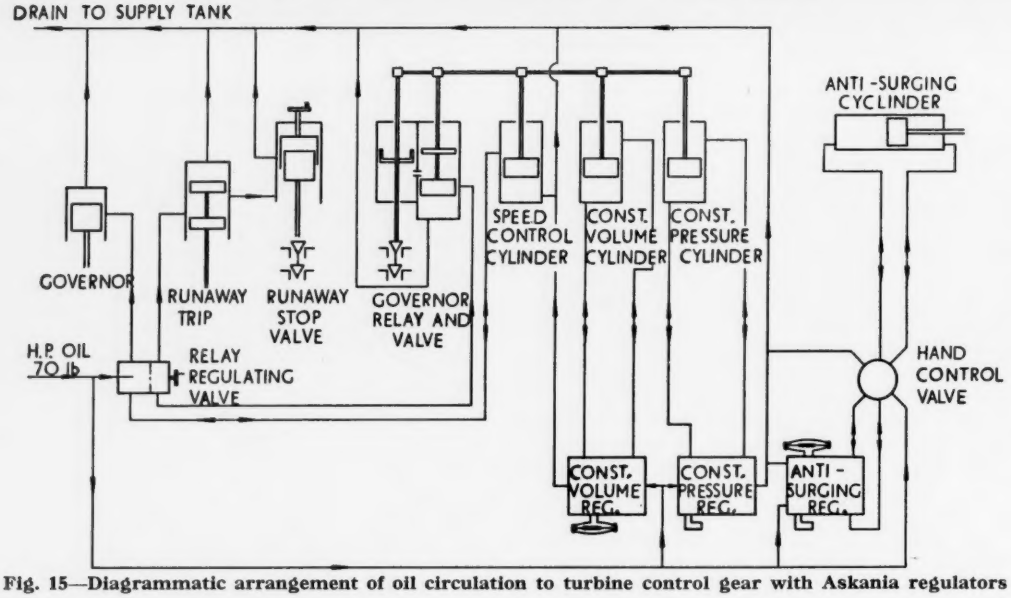


Fig. 15—Diagrammatic arrangement of oil circulation to turbine control gear with Askania regulators

high-pressure main and thence through the reducing valve to the low-pressure line. It is controlled by a pressure regulator on the lubricating circuit and is used for starting up and running down, and also cuts in automatically when the oil pressure to the bearings falls below the predetermined value. All three pumps draw their oil from the same supply tank which is fitted with a fine-mesh strainer on the oil return side. There is no provision for heating, but the low-pressure oil passes through coolers on its way to the bearings. The machine cannot be run until oil is flowing to the bearings and sufficient pressure has been built up to operate the control gear. When the machine speed is high enough to allow the main pumps to take over, the auxiliary automatically closes down. The high- and low-pressure systems are interconnected on the suction side and through the high pressure reducing valve, but as their functions are different (and for the sake of clarity), the circuit diagrams have been shown separately. The oil used in this particular system is a life guaranteed, triple inhibited turbine grade having a viscosity of 90 Rl/s at 140° F. It is cleaned up periodically while still in service by means of the station mobile centrifuge.

Blast-furnace

Exposure to the elements, an abundance of highly abrasive dust, the toxic nature of blast-furnace gas, coupled with the difficult location of many of the bearings and a continuity of operation which countenances few, if any, predictable stops of sufficient duration to permit efficient lubrication by hand methods, all contribute to the necessity of providing the modern blast-furnace with a method of lubrication which can be operated as required from a place of safety. Double-line grease systems operated on the parallel principle are frequently used for this purpose. A controller located at a point farthest from the pump, set to operate at a pressure considerably in excess of that necessary for working the metering valves, indicates by means of signal lights the completion of the cycle on hand operated units, or resets the system for the next cycle when it is fully automatic. Early experience with these systems showed that from the distributor platform upwards, small-bore steel tubing corroded badly, metering valve stems became blocked with dust and their bodies deteriorated, and the long flexible tubes necessary to follow the movement of bell beams, quadrants, and chains were extremely liable to damage by fracture or burning. By close co-operation with the equipment suppliers, considerable improvements have been made, including:

(i) Replacing steel by copper for all small bore tubing in the bell and distributor area
(ii) Ambushing pipe runs wherever possible, to avoid accidental damage and prevent dust building up on them
(iii) Arranging metering valves in groups wherever possible, housing them in protective boxes, and taking advantage of any protection afforded by existing structures when siting others. A typical 'valve group' in its protective box is shown in Fig. 16.
(iv) Fitting high- and low-pressure swivels to allow rigid pipes to be used in place of flexible rubber tubes.

On exposed sites it might be necessary to steam-trace the main supply lines and encase them in lagging, but by selecting a grease with good low temperature pumpability characteristics, the use of steam can be avoided.

Although the foregoing examples do not completely exhaust the possibilities of centralized lubricating systems on the ironmaking side of the industry, many other items will be recognized as auxiliaries which are common to many sections of the industry and can thus be considered collectively.

Auxiliary Equipment

Auxiliary equipment includes mobile items such as overhead travelling cranes, chargers, plate handlers,

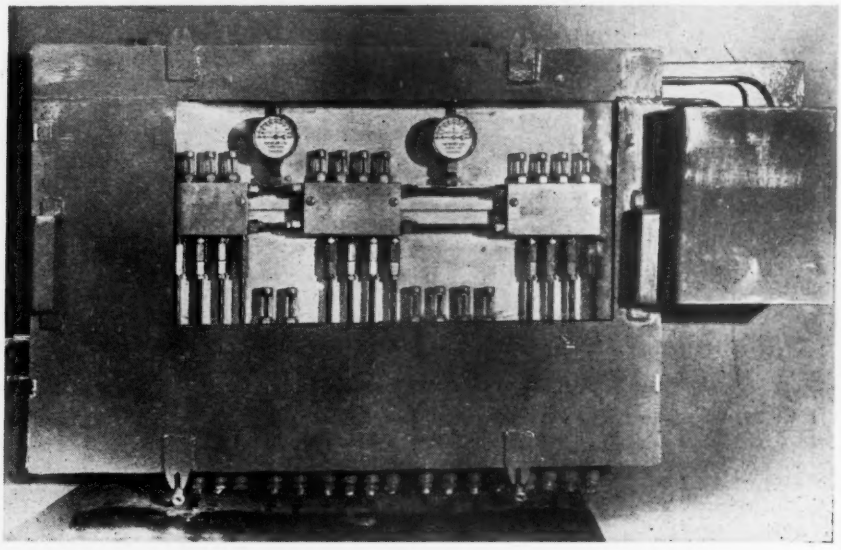


Fig. 16—Typical metering valve box suitable for blast-furnace lubrication

transfer cars, hot metal carriages, etc., and amongst the static equipment will be found shears, presses, pan mills, jaw crushers, etc. This type of machine is almost always designed for lubrication on the all-loss principle, a system which, in the absence of some type of mechanical lubricating device, usually results in alternating periods of over and under lubrication coupled with more or less frequent stoppages to allow the lubricant to be applied, or the risks involved in doing this while the machine is in motion.

Continuous operation of the major plant items depends to a large extent on the uninterrupted working of their auxiliaries. Generally in these cases, the only foreseeable stop during which lubrication personnel can attend to them will be the meal break, and unless the amount of attention demanded by each is kept to the minimum, there will be a real danger of the work being scamped or neglected altogether, particularly where such items are fairly widely dispersed or not easily accessible.

Hand application is time-wasting under any circumstances and should be avoided if possible, but where it has to be tolerated, measures can be taken to speed up the work or extend the interval between visits.

A classical example of this is the grouping of nipples on a battery plate. By substituting a metering device for the battery plate, substantial savings in time and lubricant can be made and the risks of over- or under-lubrication avoided. Figure 17 shows a 4-point positive splitter used as a master metering block on the run-out table of a 12 ft × 2 in. cold plate leveller. The capacity of the master is such that one stroke of each piston displaces sufficient lubricant to operate the 6-point slave block to which it is connected, and

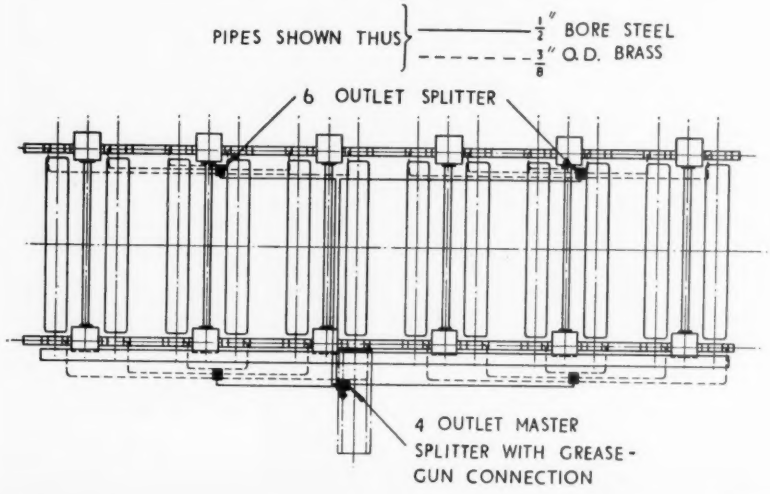


Fig. 17—Diagrammatic arrangement of grease-gun operated branched system on a run-out table

Fig. 18—Constant-level oilers fitted to shaft bearings of a shear

by attaching an ordinary hand gun to a single nipple on the master, the 24 bearings, all of which are ambushed beneath floor plates, are fed with a measured quantity of lubricant, the indicator on the master block showing when this has been done.

Fitting constant-level oilers to ring-oiled bearings, small crank cases, or oil-lubricated ball or roller bearings can also bring about economies in time and lubricant. For example, the 130-mm double row roller bearings on the main exhaust fans of a Greenawalt sintering plant were originally lubricated by 1-pt capacity drop feed oilers which required refilling at least once every 8 h. The end covers were modified to allow 4-oz constant levellers to be fitted, which resulted in an average lowering of the bearing temperatures by 5° C, a reduction in the oil consumption per bearing from 1·3 oz/h to something under 0·06 oz, and an extension of the periods between refilling of from 8 h to 3 to 4 days.

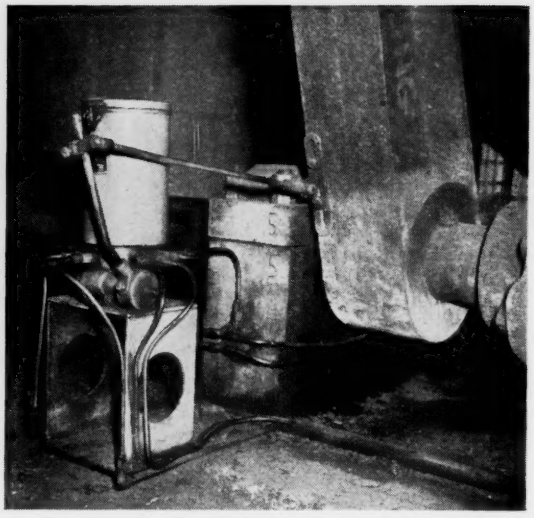


Fig. 19—Radial-type lubricator fitted to plate pushing mechanism

Figure 18 shows this type of lubricator fitted to the first motion shaft of a guillotine-type cross cut shears in the shearing line of a 7-ft plate mill. During a work study it was found that about 6½ h per week were spent on lubricating these and the similar bearings on the two side trimming shears in the line. On the average each machine was visited 75 times in the week, the reasons given being insufficient bearing-well capacity and no means of seeing the level. Since fitting constant level oilers which are visible from the floor, the only attention found necessary is the routine topping up of the bottles which accounts for less than 20 min per week.

Many of these auxiliaries are admirably suited to

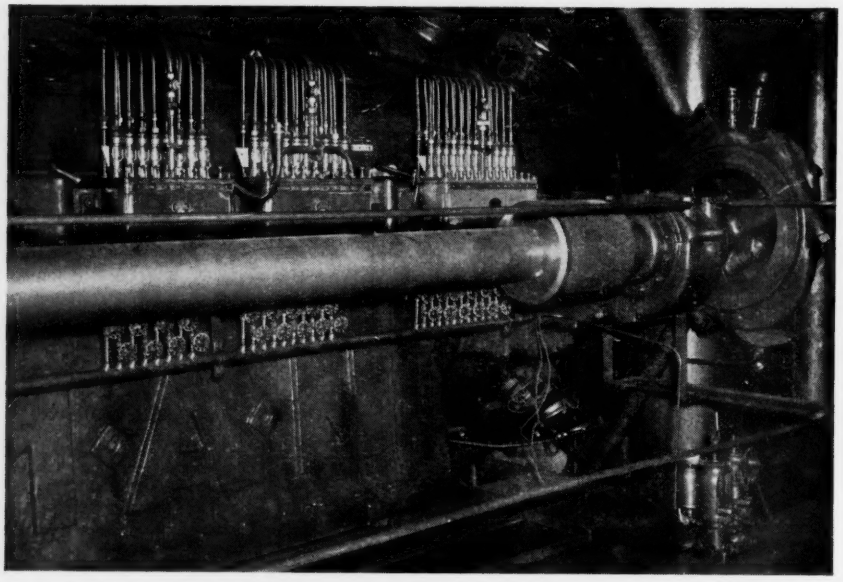


Fig. 20—'In-line' lubricators fitted to a gas-driven blowing machine

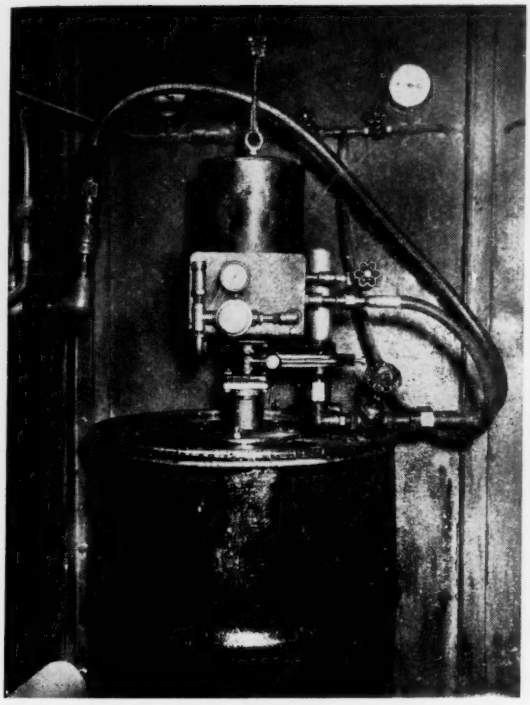


Fig. 21—Air-operated barrel pump-type greasing station

lubrication by one or other of the multi-pistoned-type mechanical force feed lubricators. By suitably connecting the driving shaft to a moving element of the machine, the first essential of relating the supply of lubricant to the working of the machine can be accomplished, and by adjusting the effective stroke of the piston concerned, the requirements of the individual bearing can be met. Thus one lubricator with the requisite number of deliveries can be successfully used to serve a machine fitted with bearings of various sizes and operating under different conditions of load and speed. By making full use of the pump capacity and fitting dividers of the type already mentioned, it is possible to lubricate a very large number of bearings from a single unit of this kind.

Figure 19 shows a typical grease or heavy oil lubricator feeding the bearings of a plate pushing mechanism. The device on the bearing pedestal is a four way positive splitter distributing the feed from one piston to four bearings.

Figure 20 illustrates the type of lubricator used for feeding light and medium viscosity oils. It is serving a large gas-driven blowing engine, and the distributing main by means of which the reservoirs can be replenished from an overhead tank is clearly visible.

Heavy overhead travelling cranes such as those used in melting shops, mills, and raw material stockyards at blast-furnace plants, can have up to as many as 100 points requiring lubrication, and if mechanized they will be fitted with several lubricators of the type shown in Fig. 19. By equipping the cranes with distributing mains permanently attached to the lubricators serving end carriages, and flexible connections for those on the crabs, it is possible to adapt the service station principle to the replenishing of the pump reservoirs. To do this, an air-operated barrel pump suitable for direct insertion into the standard 400-lb container is located at ground level and connected to a vertical header with tappings at the various track levels. The machine to be serviced is then run to a point near the header branch and the distributing main connected to it. On opening the branch valve, the distributing main is pressurized and the reservoirs of the lubricators filled in turn by operating the necessary stop valves. Apart from speeding up the servicing, this system considerably reduces the chances of the lubricant becoming contaminated, and the pumps and bearings damaged by the presence of foreign matter. The installation shown in Fig. 21 serves four ground-type chargers, three hot metal charging cranes and three stockyard bay cranes, and the average time to service one of them is about 5 min.

Where plant of the kind being considered is fitted with anti-friction bearings which demand extended periods between applications, hand-operated pumps of the compressor type can be used with advantage. These pumps deliver lubricant to metering valves, the outlets of which are connected to the points they serve. Fixed or variable output valves with or without individual indicators are available, and valves of various sizes can be incorporated in a single system. They provide a very useful and flexible means of supplying both mobile and static items of plant with controlled lubrication. The unit shown in Fig. 22 serves a hot levelling machine and is typical of the mounting and application of these valves.

The foregoing is intended to show generally the type of equipment available for the lubrication of ancillary plant, and to illustrate how it can be used to advantage. In any works, each particular machine must be considered separately, and in choosing the lubricant and the means of applying it, regard must be paid to the mechanical features and such factors as accessibility, operating temperatures, general atmospheric conditions, safety, and the overall effect of the stoppage of the item concerned, either for re-lubrication or due to lubrication failure on the plant associated with it.

Melting Shops

Melting shop equipment consists mainly of a number of individually operated machines of the type previously mentioned as auxiliaries. They are usually lubricated on the all-loss principle by either manually or mechanically operated pumps depending on whether the bearings are anti-friction or plain.

It is not uncommon for the heavier casting pit cranes to have as many as seven separate lubrication units fitted to them, each driven by the particular motion it serves.

The arrangement of the crabs of many of these heavier industrial overhead travelling cranes is admirably suited to lubrication by oil circulation. This method has not yet been adopted but its advantages include:

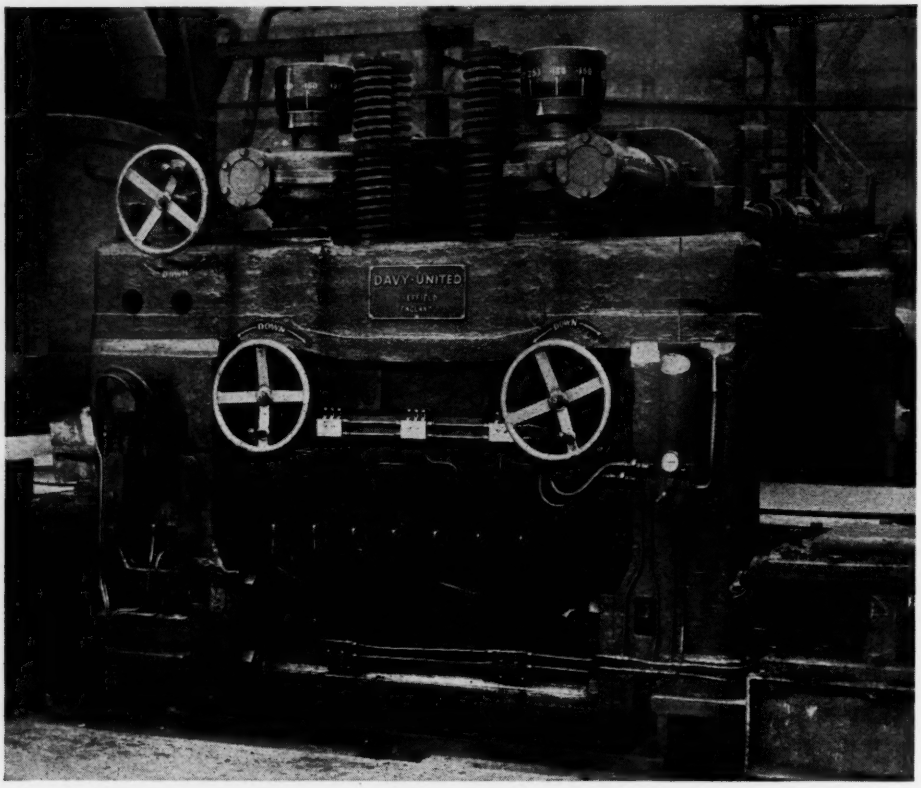


Fig. 22—Manually operated centralized greasing system fitted to hot levelling machine

(i) Spraying the gears, thus ensuring lubrication even during ' inching '
(ii) Allowing one lubricant to be used on both bearings and gears and so do away with grease, extruded from bearings, contaminating the gear oil
(iii) Permitting the filtering of the lubricant and so prevent adventitious material being carried to the rubbing surfaces
(iv) Allowing the incorporation of safety devices to prevent the machine being run without an adequate lubricant supply
(v) Securing a considerable saving in lubricant
(vi) Substantially reducing servicing time
(vii) Promoting both greater cleanliness and safety.

CONCLUSION

Any lubrication programme should aim at applying the right lubricant in the right amount, place, and at the right time, so as to assure maximum safety to personnel with minimum interference to plant operation. The large centralized systems built into or on to many of the major items of plant used in the production of iron and steel usually measure up fairly closely to this conception, whether they supply lubricant on the all-loss principle as to the open-type roll neck, or oil on the flood principle to other equipment.

In addition to the equipment so served, there will be found in almost every department many items of plant which, if not as spectacular, are equally vital for the maintenance of production and for which no provision has originally been made. With the present day appreciation of lubrication and its direct influence on preventive maintenance techniques, the knowledge of lubricants and how they can be most effectively applied, is available to all sections of the iron and steel industry. It is a question of applying that knowledge to its best advantage. To this end, the industrial lubrication engineer can make a major contribution.

Acknowledgment

The authors wish to acknowledge the courtesy of The United Steel Companies Ltd. in granting permission to produce this paper and for all the illustrations except Figs. 3 and 16. Figure 16 is reproduced by permission of Farvalube Ltd.

References

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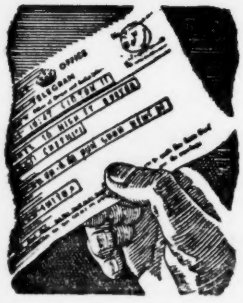

N E W S

Announcements and News of Science and Industry

THE IRON AND STEEL INSTITUTE

Annual General Meeting, 1957

The **Annual General Meeting** of The Iron and Steel Institute will be held at 4 Grosvenor Gardens, London, S.W.1, on Wednesday and Thursday, **22nd and 23rd May, 1957.** The Dinner for Members will be held at Grosvenor House, Park Lane, London, W.1 on the evening of Wednesday, 22nd May, 1957.

Special Meeting in Sheffield, 1957

The Special Meeting of the Institute which was to have been held in Sheffield in the week beginning 8th July, 1957, has been postponed, and will not be held this summer.

Special Meeting in Belgium and Luxembourg

A **Special Meeting** of The Iron and Steel Institute will be held in Belgium and Luxembourg from Tuesday, **17th June, to** Saturday, **28th June, 1958.** Further details will be announced in the *Journal* later.

Acta Metallurgica

Beginning in January, 1957, *Acta Metallurgica* is being published monthly, instead of every two months. The American Institute of Mining, Metallurgical, and Petroleum Engineers has joined the American Society for Metals, who initiated this journal in 1943, as a sponsoring society. Publication of *Acta Metallurgica* is being undertaken on behalf of the Board of Governors by Pergamon Press Inc. of New York; Professor Bruce Chalmers of Harvard University continues as Editor.

A number of societies throughout the world, including The Iron and Steel Institute and The Institute of Metals, are Co-operating Societies, and their members have the privilege of obtaining *Acta Metallurgica* at a reduced rate. Subscriptions for 1957 should be paid direct in dollars to Pergamon Press Inc., 122 East 55th Street, New York, U.S.A. The subscription for members of the two sponsoring societies is $8.00, for members of the co-operating societies $12.00, and for others $16.00.

Powder Metallurgy Joint Group

The Councils of The Iron and Steel Institute and The Institute of Metals have agreed to form a Powder Metallurgy Joint Group, to act within the existing framework of the Institutes. Full details will be announced in due course.

British Nuclear Energy Conference

Arrangements were made at a meeting of the Board of the British Nuclear Energy Conference held on 9th January, 1957, under the chairmanship of Sir John Cockcroft, O.M., K.C.B., F.R.S., for The Iron and Steel Institute and The Institute of Metals to become members of the Conference. Each Institute will be represented on the board by three members, those for The Iron and Steel Institute being Dr. H. H. Burton, C.B.E. (*President*), Mr. W. Barr, O.B.E. (*Honorary Treasurer*), and Mr. K. Headlam-Morley (*Secretary*). It had been felt for some time that the organization would be strengthened by including representatives from the field of metallurgy.

The purpose of the British Nuclear Energy Conference is to co-ordinate the activities of the constituent members in the field of nuclear energy by holding meetings and publishing a journal. The original constituent members were the Institutions of Civil, Mechanical, and Electrical Engineers, the Institute of Physics, and the Institution of Chemical Engineers.

Members of the Institute are entitled to attend meetings sponsored by the Conference and arranged by any of the constituent societies; details of meetings will be announced from time to time in the *Journal*. They can also purchase the quarterly *Journal of the British Nuclear Energy Conference*, at the reduced rate of £1 10*s*. 0*d*. per annum. Subscriptions should be paid to the Secretary of the British Nuclear Energy Conference (A. McDonald Esq., B.SC., M.I.C.E.), 1–7 Great George Street, London, S.W.1. Details of meetings on 5th and 12th March are given in the Diary (p. 411).

BESSEMER CENTENARY CELEBRATIONS

Hitchin

The Hitchin Urban District Council commemorated the centenary of the Bessemer process by a well thought-out programme on 4th December, 1956, at which the Institute was represented by the President, Dr. H. H. Burton, C.B.E., and the Secretary, Mr. K. Headlam-Morley. Arrangements were made by a committee in which Councillor W. A. Hill, Chairman, and Mr. W. Wilson, Clerk of the Council, had taken the lead.

In the morning, Mr. H. Douglas Bessemer renamed the Old Hale Secondary Modern School (Headmaster, Mr. J. T. Hardwick) the "Bessemer School for Boys" and unveiled a plaque in memory of his great-grandfather. Later, another plaque was unveiled at Charlton House, where Sir Henry Bessemer was born in 1813.

At a luncheon at the Sun Hotel, the toast of "Bessemer" was proposed by Sir Ernest Lever, President of the British Iron and Steel Federation, and Mr. Douglas Bessemer replied. Councillor Hill proposed the toast of "The New Industrial Revolution—North Hertfordshire" and the Hon. David Bowes-Lyon, Lord Lieutenant of Hertfordshire, replied.

During the afternoon a Centenary Exhibition in the Town Hall was opened by Mr. Bessemer. The arrangements had been made by Mr. G. L. Evans, Curator of the Museum, with the co-operation of the B.I.S.F., the B.I.S.R.A., and companies with local connections. The Science Museum and the Institute also lent exhibits.

NEWS OF MEMBERS

Monsieur **Marcel Adam** has been appointed Assistant Manager of La Société Sadaci, Landerbrugge, Belgium.

Mr. **Y. A. Calderwood** has returned to the London Office of the Wellman Smith Owen Engineering Corporation Ltd.

Dr. **J. G. Cockburn,** Abstractor of The Iron and Steel Institute, has been elected an Ordinary Member of Council of the Royal Microscopical Society.

Monsieur **Pierre Coheur** has been appointed to succeed Professor H. Thyssen in charge of the School of General Metallurgy, Steelworks Practice, and Metallography in the Faculty of Sciences at the University of Liège.

Mr. **H. E. Dixon** has transferred from Richardsons, Westgarth Atomic Ltd. to Atomic Power Construction Ltd., as Chief Metallurgist.

Mr. **J. J. Evans** has been appointed Manager of the Blast Furnace and Preparation plants at John Summers and Sons Ltd.

Mr. **P. R. Vaughan Evans** has joined the Physical Metallurgy section of the Metropolitan-Vickers Electrical Co., Ltd., Research Department, Manchester.

Mr. **G. Goddard** has been appointed Deputy Director Inspection (Materials) in the Aeronautical Inspection Directorate, Ministry of Supply.

Mr. **N. V. Howard** has been appointed a Local Director of Thos. Firth and John Brown Ltd.

Mr. **R. A. Iddon** has been appointed Manager of the new Margate factory of G. A. Harvey and Co. (London) Ltd.

Dr. **James T. Mackenzie** has retired from his position as Technical Director of the American Cast Iron Pipe Company; he has taken up an appointment with the Southern Research Institute, Birmingham, Alabama.

Mr. **M. K. Madhekar** has been awarded the degree of Ph.D. by Manchester University and has returned to India.

Mr. **C. D. Muntz** has been appointed a director of Woodall-Duckham Construction Co., Ltd.

Mr. **J. E. Oram** has been appointed Managing Director of Wild-Barfield Electric Furnace Co., Ltd.

Mr. **T. Powell** has been appointed Managing Director of British Acheson Electrodes Ltd. He remains a director of Union Carbide Ltd. and British Electro Metallurgical Co. (*amended notice*).

Dr. **W. I. Pumphrey** has been awarded the degree of D.Sc. in Industrial Metallurgy by the University of Birmingham for his work on hardenability, the transformation of steel during continuous cooling, and the metallurgy of welding.

Mr. **D. Rider,** O.B.E., has resigned his position as Joint Managing Director and his seat on the board of Woodall-Duckham Construction Co., Ltd.; he retains his directorship of the parent company, Woodall-Duckham Ltd.

Mr. **R. Rolls** has been awarded a B.Sc. degree in Metallurgy at the University of Durham, and has been elected a Licentiate of the Institution of Metallurgists.

Mr. **Frank Rowe,** Managing Director of K and L Steelfounders and Engineers Ltd., has been appointed a Director of the George Cohen 600 Group.

Mr. **M. N. Saxena,** Lecturer in Metallurgy, University of Roorkee, India, is shortly leaving for the U.S.A., where he will work for his research degree at the Rensselaer Polytechnic Institute.

Dr. **H. G. Taylor** is relinquishing his position as Director of the British Welding Research Association to become Director of the Electrical Research Association. He takes up his new position on 1st April.

Mr. **C. J. Thwaites** has been awarded the degree of M.Sc.(Eng.) and has been elected an A.I.M.

Mr. **H. F. Tremlett** has been appointed Deputy Director of the British Welding Research Association.

Obituary

Sir **John Craig,** C.B.E., D.L. (*Past-President, Honorary Member; elected* 1917), on 1st February, 1957.

Mr. **Reginald Stanley Crowle** (*elected* 1939), of Millom, Cumberland, on 13th December, 1956.

Mr. **James Arthur Davies** (*elected* 1922), of Wolverhampton, on 9th January, 1957.

Mr. **John E. Mercer** (*elected* 1938), of Nuneaton, on 31st December, 1956.

Mr. **Thomas Montgomery Service** (*elected* 1906), on 5th February, 1957.

Mr. **R. E. L. Tricker,** M.SC., F.I.M. (*elected* 1944), on 22nd December, 1956.

CONTRIBUTORS TO THE JOURNAL

T. A. Cosh, B.SC., A.R.T.C., F.I.M.—Head of Steelmaking Section, British Steel Castings Research Association.

Mr. Cosh was born in Glasgow, where he attended Hutchesons' Boys School. In 1935 he joined the laboratory staff at Dixon's Ironworks, and later transferred to the Empire Aluminium Co., Ltd. On the outbreak of war he enlisted in the Army, and was commissioned in the Highland Light Infantry. On demobilization in 1946 he became a full-time student at the Royal Technical College and Glasgow University; he was awarded the A.R.T.C. in metallurgy and graduated B.Sc. in metallurgical chemistry. In 1950 he was appointed Works Metallurgist to Jarrow Tube Works Ltd., and in 1952 joined the staff of the B.S.C.R.A.

H. Jones—Lubrication Engineer, Appleby-Frodingham Steel Company.

Harry Jones, who was born in South Wales, studied mining engineering, and was awarded travelling scholarships in 1918 and 1919 which enabled him to travel in the Yorkshire and Scottish coalfields respectively. On the completion of his course, he was engaged by the Coppee Company to help in starting up the coke ovens at the Redbourn Works of Richard Thomas and Co., Ltd.; he stayed on afterwards as a member of the operating staff. Mr. Jones joined the Appleby-Frodingham Steel Company in 1927, and in 1930 took up general duties in the newly-formed Engineering Research Department. In 1948, after a course with a major oil company, he took up his present position as Lubrication Engineer.

K. Sachs, M.SC., PH.D., A.I.M.—Head of Research Metallurgy Section, G.K.N. Group Research Laboratory.

Kurt Sachs was born in Vienna in 1924. In September, 1938, he crossed into Czechoslovakia, and worked there until May, 1939, when he came to the U.K. He attended Bordesley Green Junior Technical College, Birmingham, until 1941, when he joined the Mond Nickel Co., Ltd., as a laboratory assistant in their Research Laboratory. He attended the Birmingham Technical College during this time, and obtained an external London degree in 1946, which led to his being appointed to the research staff of the Laboratory. Subsequent research led to his being awarded the degrees of M.Sc. (1951) and Ph.D. (1953) of London University. Dr. Sachs joined the staff of the G.K.N. Group Research Laboratory in 1953.

J. D. Swindale, B.SC.—Scientific Officer, British Railways Research Department (*February Issue*).

Mr. Swindale was educated at King Henry VIII Grammar School, Coventry, and Birmingham University, from which he graduated with the degree of B.Sc., with Honours in Metallurgy. After two years at Birmingham University he joined the Development and Research Department of the Mond Nickel Co., Ltd., for the period 1945–1948. He returned to Birmingham University in 1948 to complete his studies, which had been interrupted by the war. Mr. Swindale took up his present appointment with British Railways in 1949.

IRON AND STEEL ENGINEERS GROUP

Thirty-third Meeting

The Thirty-third Meeting of the Iron and Steel Engineers Group of The Iron and Steel Institute will be

held at 4 Grosvenor Gardens, London, S.W.1, on **3rd April, 1957.** The Meeting will be devoted to the presentation and discussion of a paper on "*Lubrication in Iron and Steelworks*," by Mr. H. Jones (Appleby-Frodingham Steel Company) and Mr. G. D. Jordan (United Steel Companies Ltd.), which is published in this issue of the *Journal* (pp. 389–408). The morning session, from 10.30 a.m. to 12.45 p.m., will be devoted to a discussion of those aspects of the paper dealing with the role of lubricants, and the afternoon session, from 2 p.m. to 4 p.m., to a discussion on the application of lubricants. A buffet luncheon will be served in the Library.

Meetings on Air and Water Pollution in the Iron and Steel Industry

The Iron and Steel Engineers Group is arranging two important meetings on "Air and Water Pollution in the Iron and Steel Industry" in the autumn of 1957; the meetings will be held at Church House, Westminster, London, S.W.1. The meeting on "Air Pollution in the Iron and Steel Industry" will be held on Wednesday and Thursday, **25th and 26th September, 1957:** the meeting on "Water Pollution in the Iron and Steel Industry" will be held on Wednesday and Thursday, **11th and 12th December, 1957.** Approximately 20 papers will be presented at the two meetings. Preprints will be available before the meeting and the papers and the discussion will be published subsequently in the Special Report series of the Institute.

A preliminary notice is being circulated to Members immediately: a further notice giving the full programme will be circulated to Members during the summer.

THE INSTITUTE OF METALS

Joint Spring Meeting

The 1957 Spring Meeting of The Institute of Metals will be held in London from Monday to Saturday, **29th April to 4th May.** The Meeting will be a joint one with the Associazione Italiana di Metallurgia, the Société Suisse des Constructeurs de Machines, and the Schweiz. Verband für die Materialprüfungen der Technik, each of which has acted as host to the Institute in recent foreign meetings. The Opening Ceremony will take place at Church House, Westminster, W.1, on 29th April at 6.30 p.m., and will be followed by the May Lecture, which will be delivered by Sir Eric Ashby on "*Education in Science and Technology.*" The Annual General Meeting will be held the following morning at the Royal Institution, Albemarle Street, London, W.1, at 9.30 a.m., and will be followed by the Presidential Address by Dr. L. B. Pfeil, O.B.E., F.R.S. There will be a scientific session that afternoon at 2.30 p.m. at Church House. Further scientific sessions are to be held at Church House on 1st May, at 9.30 a.m. and 2.30 p.m., and on 2nd May at 9.30 a.m. A banquet at which the members of the Italian and Swiss societies will be the Institute's guests will be held at Grosvenor House, Park Lane, W.1, on the evening of 1st May at 7.15 p.m.

Works visits have been arranged for the afternoon of 30th April and all day on 3rd May. Those on 30th April include G.E.C. Ltd. (Fraser and Chalmers Engineering Works), Fredk. Braby and Co., Ltd., and Telegraph Construction and Maintenance Co., Ltd., with Submarine Cables Ltd. The all-day visits are to Cambridge, A.E.I. Ltd. Research Laboratories, Enfield Rolling Mills Ltd., Ford Motor Co., Ltd., Stewarts and Lloyds Ltd., and Northern Aluminium Co., Ltd., with Aluminium Research Laboratories Ltd.

Members of The Iron and Steel Institute have been invited to attend the Opening Ceremony, the Annual General Meeting, the banquet and dance, the works visits listed above, and the scientific sessions on the same terms as Members of The Institute of Metals. Session *A* on 1st May will be devoted to a symposium on metallurgical aspects of the control of quality in non-ferrous castings, arranged with the Institute of British Foundrymen.

Members wishing to take part in the meeting should write to the Secretary of The Institute of Metals, 17 Belgrave Square, London, W.1.

Autumn Meeting

The Autumn Meeting of The Institute of Metals will be held in Glasgow from Tuesday to Friday, **17th to 20th September, 1957,** by invitation of the Scottish Local Section.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Conference on Hydraulics

Recent developments in hydraulic controls and drives will be reviewed at a Conference arranged by the British Iron and Steel Research Association, to be held on **26th to 28th March, 1957,** at Ashorne Hill, near Leamington Spa. The chairman will be Mr. W. M. Larke of Stewarts and Lloyds Ltd., and the papers to be delivered will include the following: "Works Installations," Mr. R. L. Willott (John Summers and Sons Ltd.) and Mr. F. E. Probyn (Richard Thomas and Baldwins Ltd.); "Equipment for Steelworks," Mr. R. G. Hamilton (Stein Atkinson Vickers Hydraulics Ltd.); "Forging Press Hydraulics," Mr. F. Towler (Towler Brothers (Patents) Ltd.); "Modern Pumps and Hydraulic Motors and their Applications," Mr. F. B. Levetus (Keelavite Rotary Pumps and Motors Ltd.); "Modern Servo Control Systems," Mr. R. Hadekel (Sperry Gyroscope Co., Ltd.); "Fluidrive and its Application in the Iron and Steel Industry," Mr. A. Vickers (Fluidrive Engineering Co., Ltd.); "The Nylon Joint," Lieut. D. H. Cameron, R.N. (Admiralty Engineering Laboratory); "The Work on Seals at the Hydromechanics Laboratory," Dr. D. F. Denny (British Hydromechanics Research Laboratory); "The Work of M.E.R.L. Fluid Mechanics Division," Mr. D. Firth (Mechanical Engineering Research Laboratory).

Further information and details can be obtained from The Technical Secretary, Plant Engineering Division, BISRA Laboratories, 140, Battersea Park Road, London, S.W.11.

DIARY

4th Mar.—CLEVELAND INSTITUTION OF ENGINEERS—"The Ups and Downs of Ironmaking," by G. D. Elliot—Cleveland Scientific and Technical Institution, 6.30 P.M.

4th Mar.—EAST MIDLANDS METALLURGICAL SOCIETY—"Recent Developments in Metallography," by D. McLean—Derby and District College of Art, 7.30 P.M.

4th Mar.—INSTITUTE OF WELDING (Sheffield and District Branch)—"Brittle Fracture," by Dr. D. W. Biggs—Grand Hotel, Sheffield, 7.15 P.M.

5th Mar.—BRITISH NUCLEAR ENERGY CONFERENCE—"Behaviour of Radioisotopes in Sewage Treatment," by A. W. Kenny—Institution of Civil Engineers, 5.30 P.M.

5th Mar.—INSTITUTE OF METALS (Oxford Local Section)—"The Writing of Scientific Papers," by Dr. W. Hume-Rothery—Cadena Cafe, Cornmarket Street, Oxford, 7 P.M.

5th Mar.—INSTITUTION OF STRUCTURAL ENGINEERS—"Abbey Steelworks," by W. S. Atkins—Cleveland Scientific and Technical Institution, 6.30 P.M.

5th Mar.—SHEFFIELD METALLURGICAL ASSOCIATION—"Silicate and Alumino-Silicate Analysis," by H. Bennett—B.I.S.R.A. Laboratories, Hoyle Street, Sheffield 3, 7 P.M.

7th Mar.—INSTITUTE OF METAL FINISHING—"Modern Painting and Stoving Techniques, including Flow Coatings," by J. J. Stordy—Engineers' Club, Albert Square, Manchester, 7.30 P.M.

7th Mar.—INSTITUTE OF METALS (London Local Section)—"Gas in Light Alloys," by Dr. C. E. Ransley—17 Belgrave Square, London, S.W.1, 6.30 P.M.

7th Mar.—Leeds Metallurgical Society—"The Study of Wear and Lubrication Using Radio-isotopes," by J. B. P. Williamson—Large Chemistry Lecture Theatre, The University, Leeds, 7.15 p.m.

8th Mar.—Institution of Mechanical Engineers—Discussion on Market Research and the Engineer—1 Birdcage Walk, London, S.W.1, 6.45 p.m.

11th–14th Mar.—The Iron and Steel Institute—Meeting of Junior Engineers—Chester and Manchester.

11th Mar.—Institute of Metals (Scottish Local Section)—"Production and Uses of Rare Metals," by Dr. J. C. Chaston—39 Elmbank Crescent, Glasgow, 6.30 p.m.

11th Mar.—Junior Institution of Engineers (Sheffield and District Section)—"Reflections of 40 Years in the Steel Industry," by F. A. Hurst—Livesey Clegg House, Sheffield, 7.30 p.m.

11th Mar.—Lincolnshire Iron and Steel Institute—Annual General Meeting, followed by "The 56-in. Continuous Hot Strip Mill at Ebbw Vale," by G. Short—North Lindsey Technical College, Scunthorpe, 7 p.m.

11th–13th Mar.—National Association of Corrosion Engineers—13th Annual Conference—St. Louis, U.S.A.

11th Mar.—Society of Chemical Industry (Chemical Engineering Group)—"A Survey of Industrial Filtration," by A. P. Hosking and K. C. Salter—14 Belgrave Square, London, S.W.1, 5.30 p.m.

12th Mar.—British Nuclear Energy Conference—"An Analogue Computer for Nuclear Power Studies," by G. J. R. MacLusky—Institution of Electrical Engineers, 5.30 p.m.

12th Mar.—Institute of Metals (South Wales Local Section)—"Clad Metals," by Professor A. R. E. Singer—Department of Metallurgy, University College, Singleton Park, Swansea, 6.45 p.m.

12th Mar.—Institution of Engineering Inspection—"Galvanic Corrosion," by J. Boraston—Grand Hotel, Broad Street, Bristol, 7.30 p.m.

12th Mar.—Institution of Engineering Inspection—"X-rays and Electronics in the Welding Shop," by J. P. Gaunt—Leeds Church Institute, Albion Place, Leeds 1, 7.30 p.m.

12th Mar.—Sheffield Metallurgical Association—"Hot Planetary Mill," by H. M. Waltl—B.I.S.R.A. Laboratories, Hoyle Street, Sheffield 3, 7 p.m.

13th Mar.—Institute of Fuel—"The Work of B.C.U.R.A. on the Coking Stoker," by M. V. Murray—Institution of Civil Engineers, Great George Street, London, S.W.1, 5.30 p.m.

13th Mar.—Manchester Metallurgical Society—"Precision Casting by the Shaw Process," by N. Shaw—Central Library, Manchester, 6.30 p.m.

13th Mar.—Newport Metallurgical Society—"Modern Steelmaking Processes," by R. W. Evans—Whitehead Iron and Steel Institute, Newport, 7 p.m.

14th Mar.—Staffordshire Iron and Steel Institute—"The Value of Instrumentation in the Steel Industry," by B. O. Smith—Star and Garter Royal Hotel, Wolverhampton, 7.30 p.m.

15th Mar.—Institution of Mechanical Engineers—Discussion on Factors in the Handling of Lubricants—1 Birdcage Walk, London, S.W.1, 6.45 p.m.

15th Mar.—Manchester Statistical Society—"Some Aspects of the Steel Industry," by G. Dick—57 Mosley Street, Manchester, 5.30 p.m.

15th Mar.—North East Coast Institution of Engineers and Shipbuilders—"Failure of Welded Steel Structures," by T. W. Bushell—Cleveland Scientific and Technical Institution, 6 p.m.

15th Mar.—West of Scotland Iron and Steel Institute (joint meeting with the Engineers Group of The Iron and Steel Institute)—"Review of Some Rolling Mill Engineering Practices," by F. G. Thomson—39 Elmbank Crescent, Glasgow, 6.45 p.m.

16th Mar.—Swansea and District Metallurgical Society—"Refractories," by H. Parnham and G. Eichler—Central Library, Swansea, 6.30 p.m.

17th–21st Mar.—Mexican Iron and Steel Chamber—Second National Congress of the Steel Industry, Vera Cruz.

18th Mar.—Institution of Production Engineers (Sheffield Section)—Geo. Bray Memorial Lecture: "The Organization of Operational Research," by Stafford Beer—Memorial Hall, Sheffield, 7 p.m.

18th Mar.—Sheffield Society of Engineers and Metallurgists—"Materials of Construction in the Heavy Chemical Industry," by F. H. Keating—Engineering Lecture Theatre, St. George's Square, Sheffield, 7.30 p.m.

19th Mar.—Sheffield Metallurgical Association—"Modern Trends in Iron and Steelmaking Refractories," by Dr. H. R. Lahr—B.I.S.R.A. Laboratories, Hoyle Street, Sheffield 3, 7 p.m.

20th Mar.—Institute of Welding—"Measurement and Use of Welding Costs," by A. G. Thompson—Cleveland Scientific and Technical Institution, 7.30 p.m.

20th Mar.—Liverpool Metallurgical Society—Visit to High Speed Steel Alloys Ltd., Widnes.

21st Mar.—Liverpool Metallurgical Society—"Steels at Elevated Temperatures," by J. D. Murray—9 The Temple, Dale Street, Liverpool, 7 p.m.

21st Mar.—Society of Chemical Industry—Symposium on Corrosion of Metals—Institution of Civil Engineers, Great George Street, London, S.W.1, 9.30 a.m.

22nd Mar.—Institution of Mechanical Engineers—Annual General Meeting—1 Birdcage Walk, London, S.W.1, 6 p.m.

22nd Mar.—North East Coast Institution of Engineers and Shipbuilders—Andrew Laing Lecture: "Structural Steels for Warship Building with Some Notes on Brittle Fracture," by Sir Victor Shepheard—Literary and Philosophical Society Lecture Theatre, Newcastle upon Tyne, 6.15 p.m.

25th Mar.—Institution of Mechanical Engineers (Yorkshire Branch)—"The Use of Shot Peening to Reduce Weight," by Dr. W. R. Berry—Technical College, Bradford, 7 p.m.

26th Mar.—Institution of Naval Architects—Annual General Meeting, followed by "Iron Ore Carriers," by J. Lenaghan—10 Upper Belgrave Street, London S.W.1, 10.15 a.m.

26th Mar.—Sheffield Metallurgical Association—"The Technical Press and the Metallurgical Industry," by F. G. Montfort-Bebb—B.I.S.R.A. Laboratories, Hoyle Street, Sheffield 3, 7 p.m.

26th–28th Mar.—British Iron and Steel Research Association—Conference on Hydraulics—Ashorne Hill, Leamington Spa.

27th Mar.—Institute of British Foundrymen (London Branch)—"Latest Practices in Shell Moulding and Coremaking," by D. H. Scott—Constitutional Club, Northumberland Avenue, London, W.C.2, 7.30 p.m.

27th Mar.—Institute of Fuel—Papers on Dust Deposition and Atmospheric Pollution—Institution of Civil Engineers, Great George Street, London, S.W.1, 5.30 p.m.

28th Mar.—Ebbw Vale Metallurgical Society (Joint Meeting with The Iron and Steel Institute)—"The Special Steel Maker and Power Generation," by Dr. C. Sykes—Lecture Theatre, Richard Thomas and Baldwins, Ltd., 7.15 p.m.

29th Mar.—Ebbw Vale Metallurgical Society—Annual Dinner.

29th Mar.—Institution of Mechanical Engineers—"Rotary Shaft Seals—"The Sealing Mechanism of Synthetic Rubber Seals running at Atmospheric Pressure," by E. T. Jagger—1 Birdcage Walk, London, S.W.1, 6 p.m.

TRANSLATIONS SERVICE

(The previous announcement was made in the February, 1957, issue of the *Journal*, p. 268).

Translations Available

No. 516 (German). O. Emicke and K. -H. Lucas: "Factors Influencing the Accuracy of the Rolling of Sheet and Strip and their Control by Experiment and by Calculation." (*Neue Hütte*, 1956, vol. 1, Mar., pp. 257–274).

No. 517 (German). W. Kafka: "A New Method of Electrode Control with Magnetic Amplifiers." (*Stahl u. Eisen*, 1956, vol. 76, Apr. 5, pp. 381–387; Discussion, pp. 387–389).

No. 518 (French). J. Moreau: "A Study of Scales Formed on Ingots." (*Revue de Métallurgie, Mémoires*, 1956, vol. 53, No. 9, Sept., pp. 703–714). (Translation prepared by Mr. A. J. Jochem, and made available through the courtesy of The Steel Company of Wales Limited).

Translations in Course of Preparation

(French). J. Calmettes and J. Drain: "The Determination of Nitrogen in Steel by a Wet Method." (*Revue de Métallurgie, Mémoires*, 1956, vol. 53, Sept., pp. 682–688; Discussion, p. 688).

(Russian). T. P. Kolesnikova and A. M. Samarin: "Influence of Manganese, Chromium and Vanadium upon the Surface Tension of Molten Iron." (*Izvestiya Akademii Nauk, S.S.S.R.*, 1956, No. 5, May, pp. 63–69).

(Russian). G. G. Oreshkin: "Experimental Running of a Blast-furnace with an Unconventional System of Cooling the Inwall and Bosh Parallel." (*Metallurg*, 1956, No. 3, pp. 1–7).

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ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

Iron and Steel Manufacture and Related Subjects

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MINERAL RESOURCES

Iron Deposits of Luxembourg and the Saar. (*Echo Mines*, 1956, Apr., 201–203; May, 267–268).

Metalliferous Deposits of the Eastern Pyrenees. G. Rodriguez. (*Echo Mines*, 1956, Mar., 137–140; May, 269–272; Jun., 332–333). Iron and other ores are listed and mapped. Some mines are described and outputs indicated.

The Formigueiros (Lugo) Ore Deposits. P. Hernandez Sampelayo. (*Inst. Hierro Acero*, 1956, **9**, May, 561–577. Special Number). [In Spanish]. Details are given of the mineralogical structure of this district and the proposed development is discussed.—P. S.

Manganiferous Iron Ores of Portugal. J. M. Cotelo Neiva. (*Inst. Hierro Acero*, 1956, **9**, Apr., 359–363. Special Number). [In Spanish]. The geology and mineralogy of the Alentejo district deposits in Southern Portugal are described. Reserves are estimated at over 10 million tons and consist principally of lepidocrocite and pyrolusite.—P. S.

Mineral Facts and Problems. (*U.S. Bur. Mines, Bull.*, 556, 1956, pp. 1042). **Iron.** W. Holliday. (371–398). A review of ores and mining, beneficiation, and use is given including many tables of statistics of resources, mines and imports into the U.S.

Brecciated Manganese Deposits in Johnson County, Tenn. R. C. Hickman. (*U.S. Bur. Mines, Rep. Invest.*, 5240, 1956, June, pp. 14). Analyses and beneficiation tests are given.

ORES—MINING AND TREATMENT

The Development of the Luxembourg Mining Industry. A. Faber. (*Rev. Tech. Luxembourg.*, 1956, **48**, Apr.-June, 87–94). An historical review of the development of iron ore mining in Luxembourg is presented. Recent progress is considered in detail.—B. G. B.

Magnetite Concentrates to Supplement High-Grade Iron Ore. E. C. Wright. (*Metal Progress*, 1956, **70**, Sept., 97–102). A general review of the beneficiation of magnetite and haematite low grade ores in the U.S.A. is presented. Concentration techniques and pellet hardening are discussed.—B. G. B.

Taconite Gives New Life to Mesabi. (*Iron Age*, 1956, **177**, Apr. 12, 55–58). The position of taconite mining and preparation is reviewed. The 6 companies producing taconite have an immediate target of 13 million tons of pellets, and the planned annual tonnage is 34 millions.—D. L. C. P.

Experience with Impact Crushing in Mining, Ore Dressing, and Metallurgy. E. Puffe. (*Zeit. Erz. Metal.*, 1955, **8**, Dec., 570–580). A comprehensive review, with reference to coal and iron ores among many other products, is presented.

'Quick Quench' Steel Balls for Ore Grinding. G. Mounsey. (*Canad. Metals*, 1956, **19**, July, 36–37). A brief description of a plant for the production of 2 in. dia. steel balls for grinding purposes at the mill site is given.—B. G. B.

Development of Iron Ore Pelletisation. K. Meyer. (*Stahl u. Eisen*, 1956, **76**, May 17, 588–595). After an historical introduction, the author discusses features of the pelletization process. Allusion is made to the choice of raw material, and the effect of pellets on blast furnace and sintering operations.

Weirton's New 8-foot Wide Iron-ore Sintering Plant. J. H. Strassburger. (*Amer. Inst. Min. Met. Eng.*, 1956, *Preprint*). A description is given of the new 8 ft wide sintering machine at Weirton Steel Co. and of its auxiliary handling and processing equipment. It has a nominal production capacity of 2500 tons per day, based on 3·0 tons per day per ft² of active grate area.—G. F.

Report of the Work of the Committee on Ore Sintering Presented to the Third General Assembly. (*Inst. Hierro Acero.*, 1956, **9**, July, 858–870. Special Number). [In Spanish]. A brief résumé of the studies of this committee, which is principally concerned with the sintering behaviour of the Oronera carbonate ores from the Arboleda zone, is given. The results show that it is possible to sinter crude and calcined ores separately, or mixed together, or with other ores, on an industrial scale. An extremely high degree of desulphurization is obtained. It appears possible to sinter crude carbonate ore directly, thus eliminating the calcination process.—P. S.

Development of the Dwight-Lloyd Sintering Process. H. E. Rowen. (*J. Met.*, 1956, **8**, July, 828–831). The early methods of ore beneficiation are outlined and their development to the modern Dwight-Lloyd sintering method is discussed.—G. F.

Design and Operation of No. 3 Sinter Strand at Jones and Laughlin's Benson Mines. R. G. Fleck and F. M. Hamilton. (*Amer. Inst. Min. Met. Eng.*, 1956, *Preprint*). The design and operation of the Benson No. 3 sinter strand are discussed, and brief details are given of the wind system, raw materials and product handling, and instrumentation and controls. Operating experiences are summarized.—G. F.

The Effect of [Quicklime] Additions upon the Production and Quality of Iron Ore Sinters. J. A. Boned Sopena. (*Inst.*

Hierro Acero, 1956, **9**, Apr.-June, 656–667). [In Spanish]. Pilot tests on Sierra Menera ore sinters have indicated that a 2% quicklime addition has a beneficial effect. Approximately 20% increases in production, sintering intensity, sinter strength, and reducibility are obtained provided that the charge is aged for one hour after the addition, before sintering. An explanation for the effects of lime is given together with a discussion of the constitution and structure of the sinters. (12 references).—P. S.

A Metallographic Study of Renn-Krupp Nodules. F. Muñoz del Corral, J. A. Boned Sopena and J. M. Bermudez de Castro y Mosquera. (*Inst. Hierro Acero*, 1956, **9**, May, 578–585). [In Spanish]. An examination of the nodules produced by the beneficiation of low-grade, oolitic, Asturian ores (28–45% Fe, 0·5–0·9% P) is described. These nodules are coated with oxide and an opaque glassy slag, and consist of grains of decomposed austenite bonded with a phosphide eutectic together with numerous iron sulphide and siliceous inclusions. This evidence provides several objections to the existing theory of nodule formation and it is suggested that high-carbon, impure iron liquids form first and that these begin to solidify as they lose carbon, rejecting impurities into the surrounding liquid.—P. S.

The Crystal Structure of Ferrocarpholite. C. H. MacGillavry, W. L. Korst, E. J. W. Moore and H. J. van der Plas. (*Acta Crystallographica*, 1956, **9**, Oct., 10, 773–776).

Is Coal a Useful Source of Metals? I. Berkovitch. (*Chem. Progress Eng.*, 1956, **37**, Sept., 305–307). Iron oxide may be up to 30% of ash.

FUEL—PREPARATION, PROPERTIES, AND USES

Report of Committee D-5 on Coal and Coke. (*Amer. Soc. Test. Mat. Preprint No.* 36, 1956). A draft specification for the determination of the equilibrium moisture of coal at 96 to 97% relative humidity and 30° C is proposed.—B. G. B.

Hardness of Coal. H. Honda and Y. Sanada. (*Fuel*, 1956, **35**, Oct. 451–461). The Vickers hardness and microstrength of fourteen coals of every rank have been determined.

Furnace Fuels and Their Applications. J. L. Adamson and W. Somerville. (*Inst. Hierro Acero*, 1956, **9**, May, 512–518. Special Number). [In Spanish]. A summary of the main characteristics of liquid and gaseous fuels is given and followed by examples of suitable burners. The factors involved in the choice of fuel, and the use of substitute fuels, are discussed. Typical furnace installations are illustrated.—P. S.

Perox Plant for Removal of Hydrogen Sulphide from Coke Oven Gas. H. Brommer and W. Luhr. (*Stahl u. Eisen*, 1956, **76**, Apr. 5, 402–406). Dry and wet methods of de-sulphurizing coke oven gas are reviewed. The principle of the Perox method, its industrial application, and the economics of the process are discussed.

Developments and Features of Higher Coke Oven Chambers. H. J. von Massow and H. von Holt. (*Yearbook Coke Oven Man. Assoc.*, 1956, 291–309). Design and operation is described, with discussion.

Milling Coke for Coking. II. (Disintegrators and Hammer Mills). V. Charvát. (*Paliva*, 1956, **36**, (6), 185–192). [In Czech]. In this paper, the effect of various technological variables on the efficiency of disintegrators and hammer-type mills and on the fineness of the resulting particles are discussed. The effect of the principal variables was studied experimentally, and the results are tabulated or presented by graphs. Some conclusions relating to the suitability of various types of mill and mill aggregates are derived from the data, and desirable developments for the improvement of mill control and the reduction of particle size are considered.

Coal Quality Control at the Mine by Rapid Carbonization. A. H. Brisse and P. L. Richards. (*Amer. Inst. Min. Met. Eng., Blast Furn. Coke Oven Raw Mat. Comm.*, 1955, **14**, 265–276). The application of rapid carbonization in conjunction with a well-planned and predetermined sampling procedure has proved to be extremely effective as a means of coal quality control applied to the direction of operations at the mine. Details of the control method are given.—G. F.

Coal Carbonization: Relation of Charge Density of Coal to Carbonizing Behavior. D. A. Reynolds, D. E. Wolfson, and F. W. Smith. (*Amer. Inst. Min. Met. Eng., Blast Furn. Coke Oven Raw Mat. Comm.*, 1955, **14**, 224–239). The authors have carried out tests on 11 different coals and 6 blends, each at several bulk densities, to relate coal charge density to carbonizing properties. The yields of carbonization products, heating value of the gas, and physical properties of the coke are correlated, and the data are used, along with results obtained by other investigators, to determine relationships between charge density of coal and its expansion in both sole-heated and slot-type ovens.—G. F.

Natural Gas as Fuel. K. Gythmann. (*Stahl u. Eisen*, 1956, **76**, May 31, 678–689). The compositions of natural gases occurring in various localities are given. Industrial use is discussed. German supplies and Italian developments are reviewed. The firing of steelworks furnaces with natural gas is described.

AIR POLLUTION AND SMOKE

Prevention of Atmospheric Pollution by Iron and Steel Works: Pease-Anthony Venturi Scrubber. (*Iron Coal Trades Rev.*, 1956, **173**, July 20, 157–159). Tests have been carried out at the Redcar works of Dorman Long & Co. Ltd. during oxygen lancing of iron in the ladle, to determine the suitability of the Pease-Anthony venturi scubber under operating conditions. The results show that the scrubber cleans the fume with an efficiency of more than 99·5%, and at a cost of about 6d per ton of iron treated.—G. F.

The Treatment of Corrosive Fumes. I. Fume Removal Equipment. (*Corrosion Prevention and Control*, 1955, **2**, July, 28–32). Some of the fume removal equipment currently available is briefly reviewed with particular emphasis on the use of P.V.C. and polythene in the construction of such equipment.—L. E. W.

25 Years of Dust Investigations in Steel-works. K. Guthmann. (*Stahl u. Eisen*, 1956, **76**, May 3, 558–564). A summary is given of a paper delivered in Essen to a combined meeting of the V.D.I., the Vereinigung der Grosskesselbesitzer, and the Technischer Überwachungsverein. The history of the study of smoke and dust is stated to be coeval with the history of mankind. It is a century since suitable measures were first sought to overcome the problems of flue gas and blast furnace gas. In the last 25 years dust-content measurement in steel-works has been perfected. Determinations of dust emission from steelworks have mainly been made in Germany, England, the U.S.A. and Soviet Russia. The elimination of dust and gas emission from blast furnaces has practically been achieved. The author goes on to review progress with sinter plant, furnaces, rolling mills, forges etc. He discusses dust deposition in various parts of the world and considers the effect of wind direction.

Low Maintenance Cost Reported for Cupola Dust Collector. T. A. Dickinson. (*Foundry*, 1956, **84**, July, 112, 114, 115, 117). A dry smoke control unit installed at the Alhambra Foundry Co., Alhambra, Calif. is described and operating experiences are briefly reviewed. The unit uses a series of radiant air-cooling flues to cool the outlet gas to a point where it can be filtered through silicone-impregnated glass fabric bags.

No Smoking for Kaiser. (*Steel*, 1956, **138**, Apr. 16, 100–103). The installation and experience of the electrostatic precipitator on Kaiser Steel Corps. No. 9 O.H. furnace is described. Advantages are expected from automatic voltage regulation.

Electrostatic Cleaning of Gases. B. K. Johnsen. (*Tek. Ukeblad*, 1956, **103**, May 17, 455–462). [In Norwegian]. In a review of the applications of electrostatic precipitators in the metallurgical, cement and cellulose industries the author deals with precipitator theory, design, voltage regulation, mechanical equipment (plate and tubular filters) and filter efficiency.—G. G. K.

A Portable Instrument for Respirable Dust Sampling. R. J. Hamilton. (*J. Sci. Instruments*, 1956, **33**, Oct., 395–399).

TEMPERATURE MEASUREMENT AND CONTROL

An Optical Method of Flame Temperature Measurement. I. Theory. F. J. Weinberg. (*Fuel*, 1956, **35**, July, 359–363). A simple optical system is described in which parallel light confined by a narrow slit traverses a flame and gives rise to a curved image of the slit on a photographic plate. The deviation of the image of the slit from the straight line is correlated with the final flame temperature and other flame parameters.

An Optical Method of Flame Temperature Measurement. II. Sensitivity and Applications. J. Reck, K. Sumi and F. J. Weinberg. (*Fuel*, 1956, **35**, July, 364–369). (*See* previous abstract). The application of this technique to the study of the effect of inhibitors on flames and to the determination of quantities other than the flame temperature are described.

The B.I.S.R.A. Suction Pyrometer for Open-hearth Furnace Air Uptakes. R. Barber, D. Meachen, and W. Bateman. (*J. Iron Steel Inst.*, 1957, **185,** Mar., 343–347). [This issue].

Improved Arrangements for Temperature Control of Furnaces in Type-VP-8 Installations. V. S. Ivanova and M. P. Vorob'ev. (*Zavodskaya Laboratoriya*, 1955, **21,** (8), 992–993). [In Russian]. Circuit diagrams are given for an arrangement whereby the temperature of furnaces being used for long-term strength tests can be controlled to within 2·5° C.—S. K.

REFRACTORY MATERIALS

Report of Committee C-8 on Refractories. (*Amer. Soc. Test. Mat. Preprint No.* 20, 1956). A number of revisions to A.S.T.M. standards dealing with refractory materials are proposed and details of a draft specification for the chemical analysis of refractory materials are given.—B. G. B.

Tests on Tar-Dolomite Mixes. J. Baron. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1956, **13,** (1), 133–142). Solvent extraction using Soxhlet and Feddeler methods are compared, and advantages of the latter are discussed. Results of tar estimations by extraction and combustion are given. Methods of density determination are outlined.—T. E. D.

"DenSyl" Silica Brick: Manufacture at General Refractories Plant. (*Iron Steel*, 1956, **29,** June, 309–310). Brief details are given of the development of the "DenSyl" silica brick, now being made at the new plant of General Refractories Ltd. near Bawtry. The raw material used is cretaceous flint, previously held to be unsuitable.—G. F.

New Concepts in Engineering, a Feature in the Production of Silica Refractories. (*Refract. J.*, 1956, **32,** June, 269–277). The new General Refractories plant at Austerfield, making 'DenSyl' super duty silica bricks is described. The latest automatic plant is installed, controlled from a central control room. The bricks are used where conditions are severe, including open hearth roofs.—D. L. C. P.

Suggested Classification of Fireclay Refractory Brick. A.S.T.M. subcommittee IX. (*Amer. Soc. Test. Mat., Proceedings*, 1955, **55,** 397–398). Six headings are suggested: Super Duty, High Duty, Semi-silica, Medium Duty, Low Duty and Alumina-Diaspore.

Some Changes in the Properties of Refractories at High Temperatures. C. Bodsworth. (*Iron Steel*, 1956, **29,** June, 297–301, 322). The author discusses how the properties of refractories may change in service at high temperatures. The continuation of structural changes not completed in firing, including the properties of "bloating" and bursting expansion, are considered, and contamination by liquid and gaseous impurities is described.—G. F.

Endurance Tests on Firebrick. K. Konopicky and W. Lohre. (*Stahl u. Eisen*, 1956, **76,** Jun. 14, 749–756). The authors give an appraisal of the literature on the softening of fire-resistant brick. Analogue models representing the flow of ceramic materials are described. Conditions required for endurance testing under load are stated, and suitable temperatures suggested for various types of brick. Flint glass calibration standards for checking the uniform temperature installation are described.

Study of Thermal Shock in Refractories. M. François. (*Chaleur et Ind.*, 1956, **37,** June, 143–158, July, 195–207). The face of the refractory is heated with a standardized gas flame for 10 minutes and during the first five minutes of cooling cracks are looked for. Many tests are described. A method for making observations on samples under compression is given.

IRON AND STEEL—GENERAL

Present Preoccupations of the West German Iron and Steel Industry. G. Schroeder. (*Stahl u. Eisen*, 1956, **76,** May 31, 661–668). Problems of domestic and foreign markets, economics, politics, and administration are discussed.

Aspects of the German Iron and Steel Industry. G. Grenier. (*Echo Mines*, 1956, Aug., 445–447). Statistical.

Latins Boost Steel Output. (*Steel*, 1956, **138,** May 21, 74–75). Plans for increasing steel production in the South American countries are indicated. Output will double by 1960, but still be less than 2% of world capacity.—D. L. C. P.

Development of India's Iron and Steel Industry. (*Iron Coal Trades Rev.*, 1956, **172,** May 11, 631–633). Details are given of the development plans for the Indian iron and steel industry. Particular attention is given to the Durgapur plant, which will have an initial capacity exceeding 1 million ingot tons a year, and will be built for the Indian Government by a consortium of British firms known as the Indian Steelworks Construction Co. Ltd.—G. F.

Survey of Steel in Australia: An Outline of the B.H.P. Group. (*B.H.P. Rev.*, 1956, **33,** June, 16–22).

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Coke Combustion in the Blast Furnace in the Zone Close to the Tuyeres. J. Šárek. (*Hutník*, 1956, **6,** (6), 167–168). [In Czech]. Results obtained in recent researches on combustion relations in the hearth zone of the blast furnace in England, the U.S.S.R. and the U.S.A. are discussed.—P. F.

Operation of the Blast Furnace with Zero Top Pressure. Its Advantages and Method of Achieving it. V. M. Litchinko (*Chaleur et Ind.*, 1956, **37,** May, 121–140). The advantages of low cost, cheap control and ease of conversion of existing plants are explained. Details of plant design are discussed in relation to pump requirements and layout. The problem of safety is mentioned and practical details of control and measurement in such a system are discussed.—T. E. D.

Heat Diagram for Blast Furnaces. P. Reichardt. (*Stahl u. Eisen*, 1956, **76,** June 14, 731–738). The author explains the diagram by means of a simple example. He deals with the calculation and diagrammatic representation of heat content and heat requirement of the burden, the available heat of the gas stream, temperature drops in individual zones, the influence of wall losses, the theoretical minimum fuel requirement, the effect of the state of the burden on temperature drops and fuel consumption, carbon dioxide expulsion, the use of burnt lime, and the method of accounting in the diagram for the oxygen in the iron oxides.

Operating Experience with Low Shaft Furnaces in the German Democratic Republic. H.-J. Lux. (*Neue Hütte*, 1956, **1,** Feb., 216–225). The correlation between productivity, burden yield, and specific coke consumption is discussed; the peculiarities of BHT coke are described; results of oxygen blast experiments on the Maxhütte furnace are reported; plans to reduce coke consumption by crushing and sieving the burden and operating furnaces at higher gas pressures are surveyed.—L. J. L.

On the Horizontal Distribution of Materials in the Throat. B. N. Zherebin. (*Stal'*, 1955, (9), 782–787). [In Russian]. The reasons for uneven distribution of materials in the blast furnace throat and the possibilities of overcoming them are discussed, special reference being made to the views of V. K. Gruzinov. Distributions for furnaces working on ore mixtures and sinter are plotted for various charging cycles and the distribution of the fines of each material indicated. Carbon dioxide contents of the gas at the stockline are shown for various furnace working conditions, and are related to material distribution. Recommended procedures for avoiding channelling in the stock column are listed.—S. K.

How High Grade Iron Ores And Agglomerates Will Affect Coke Rates. J. Griffen. (*J. Met.*, 1956, **8,** Apr., 439–442). The author collects and summarizes the available data on the performance of blast furnaces using high-grade iron ores and agglomerates, giving particular attention to the improvements in coke rates. Some of the problems to be solved in obtaining the maximum benefits from these new iron-bearing raw materials are discussed.—G. F.

A Comparison of Some Theories of the Blast Furnace. W. Kuczewski. (*Hutnik*, 1955, **22,** (7/8), 228–237). Older blast furnace theories are compared to Russian theories in the light of recent Russian experiments, and it is concluded that insufficient emphasis has been given in the past to reactions taking place between 450° and 650° C. The reactions: $3Fe + 2CO = Fe_3C + CO_2$, and $4CO + 2FeO = 3CO_2 + C$ are used to explain the observation that the degree of direct reduction is practically unaltered under conditions where a decrease in coke consumption per ton of iron is obtained while a higher amount of coke is burnt at the tuyeres.

Some Factors Affecting the Blast Furnace Process. W. Kuczewski. (*Hutnik*, 1955, **22,** (10), 358–362). The major faults of irregular blast furnace running are traced to bad preparation of the burden, in particular any departure from an optimum particle size of 70 mm dia. Large ore and flux particles, and an excessive percentage of fines are shown to lead to hanging. Increasing the blast pressure reduces the

problems due to differential flow of the burden, and leads to an acceleration of diffusion reactions. The time spent by iron ore in the furnace is thereby reduced, and increased productivity can be obtained without increasing the furnace volume.—W. E. & A. P. M.

Primary and Secondary Factors in the Blast Furnace. W. Kuczewski. (*Hutnik*, 1955, **22**, (7/8), 237–240). Blast furnace processes are divided into (*a*) chemical, (*b*) thermal, and (*c*) mechanical stages, and the over-riding importance of the mechanical factors is emphasized. While it is admitted that chemical and thermal factors control the theoretical progress of reactions in all parts of the furnace, the practical values of the thermodynamic parameters concerned is shown to be very sensitive to mechanical factors such as the method of feeding, burden distribution, and gas pressure. It is therefore concluded that large increases in productivity could be profitably obtained by attacking the mechanical factors rather than trying basically to alter the thermal and chemical reactions.—W. E. & A. P. M.

Blast Furnace Oxygen Operation. J. H. Strassburger. (*Blast Furn. Steel Plant*, 1956, **44**, June, 626–635). A description of a 450 ton/day plant producing 95% purity oxygen at the Weirton Steel Company, U.S.A. is given. The oxygen is used in the blast furnace and steel plants. Oxygen enrichment of the air for blast furnace operation up to 3% has been used but normal operation is 1 to 1·5% enrichment. Blast furnace operating data is given and a 1·5% enrichment of the air blast gives a 7% increase in iron tonnage.—B. G. B.

Extracting Metal from the Slag Pits of the Severskiĭ Works. G. B. Iserson and A. A. Karmanov. (*Stal'*, 1955, (9), 842–844). [In Russian]. The plant and methods used for the extraction of ladle skulls and other metal from slag deposits at an iron and steel works are briefly described.—S. K.

Prospects for the Development of the Electric Blast Furnace Industry. P. G. Ravdel'. (*Stal'*, 1955, (9), 846–848). [In Russian]. The development of the electric blast furnace, the suitability of iron making by such methods in relation to conditions prevailing in a given region is discussed. Both high and low-shaft electric blast furnaces and newer processes such as the Lubatti are considered. The results of calculations on the economics of smelting in electric and ordinary coke blast furnaces are outlined. These indicate that the capital charges for electric pig-iron are slightly the higher, but that the productivity of the electric process per worker is about five times that of the coke blast furnace when all ancillary operations are taken into account. It is concluded that the electric process is attractive for regions like eastern Siberia.

A Report on Solid Movement in Blast Furnace Models. J. B. Wagstaff. (*Amer. Inst. Min. Met. Eng., Blast Furn. Coke Oven Raw Mat. Comm.*, 1955, **14**, 298–320). The author has investigated the movement of the stock column in the blast furnace by means of a "slice" model and a semi-circular model. The movement was only slightly affected by stock-line contour, but greatly affected by the way the solid was removed and by the amount of air blown through the model. Excess fines developed a tendency to "hanging" in the furnace.—G. F.

Applications in the United States for Some European Improvements in the Blast Furnace Field. D. Petit. (*Amer. Inst. Min. Met. Eng., Blast Furn. Coke Oven Raw Mat. Comm.*, 1955, **14**, 291–295). The author suggests the use in American blast furnace practice of recent European inventions or processes connected with free-expansion coke ovens, blast furnace stoves, low-temperature distillation, and de-airing of coke oven charges.—G. F.

On the Relationship between the Gas Distribution in the Stack and the Composition of Gas in the Hearth of a Blast Furnace. I. A. Suchkov and N. N. Chernov. (*Izvest. Akad. Nauk, S.S.S.R., Otdelenie Tekn. Nauk*, 1956, (5), 52–62. [In Russian]. Analyses of gas compositions along two diameters at right angles in the throat, and gas composition and pressure drop along the diameter in front of tuyeres under different conditions of operation of a blast furnace were carried out. It was found that the distribution of the composition of gas in the hearth is interrelated to that in the throat: a peripheral flow of gas in the throat corresponds to an overloaded hearth and vice versa. Normal distribution of gases in the hearth is characterized by a concentration of CO in the centre of the hearth which should not exceed 45–50%. An increase of the concentration of CO in the centre of the hearth above 50% indicates that the distribution of the gas stream in the stack is unsatisfactory. On cooling the size of the combustion zone (as measured by the distance from the tuyere nozzle at which CO_2 disappears) increases. The evaluation of the size of the combustion zone on the basis of the point at which CO disappears, seems to be incorrect. The size of the coke circulation zone in the radial direction is a more reliable measure of the size of the combustion zone. A low concentration of CO in the centre of the hearth (45–46%) with simultaneous low concentration of CO_2 in the centre of the throat (2–3%) indicates that the furnace has a tendency to become cold.—V. G.

Operating Experiences with High Beneficiated Burdens. D. Joyce, W. P. Dowhaniuk, and B. Marsden. (*Amer. Inst. Min. Met. Eng.*, 1956, *Preprint*). A summary is given of the experiences at Algoma Steel Corporation on the use of sinter and beneficiated burden materials over the last five years. Operating data showing improved furnace performance are given.—G. F.

Desulphurization of Blast Furnace Iron with Injected Calcium Carbide. D. E. Watkins and J. R. McFarland. (*Amer. Inst. Min. Met. Eng.*, 1956, *Preprint*). Details are given of a method of desulphurizing iron by injecting calcium carbide. The method is consistent and reproducible, and the injecting equipment is simple to operate, install, and maintain. Typical operating results are presented.—G. F.

The Desulfurization of Molten Iron. J. N. Hornak and E. J. Whittenberger. (*J. Met.*, 1956, **8**, Apr., 425–429). The authors discuss three general methods of desulphurizing iron, depending on composition change with temperature drop, reaction between liquid reagents and molten iron, and reaction between solid reagents and molten iron. Attention is given chiefly to the last category, and a description is given of a fluidised-injection technique, using calcium carbonate, burnt lime, calcium carbide, or calcium cyanamide. Operating data are given, and the advantages of the method are discussed.

Rate of Desulphurization of Iron by Blast-furnace Type Slags. W. O. Philbrook and G. Derge. (*Amer. Inst. Min. Met. Eng., Blast Furn. Coke Oven Raw Mat. Comm.*, 1955, **14**, 350–362). A comprehensive summary is given of work carried out over a period of years on the kinetics and mechanism of desulphurization of iron. The effects of temperature, slag composition, and alloying elements are considered, and observations substantiating the accepted sequence of reactions are made. The results are discussed and interpreted in terms of modern slag chemistry, and their relation to blast furnace practice is outlined.—G. F.

A Comparison of Blast Furnace Penetration with Model Studies. J. B. Wagstaff and W. H. Holman. (*Amer. Inst. Min. Met. Eng.*, 1956. Preprint). The penetration of air in blast furnace models has been studied and the results are shown to be in agreement with blast furnace data. Results obtained by "rodding" the tuyeres are examined critically, and the variance between the figures at the different tuyeres is discussed.—G. F.

Solids—Gas Contacting. Close-up of a Key Tool in Metallurgy. R. E. Vener. (*Eng. Min. J.*, 1956, **90**, July, 78–91). A comprehensive review of the whole field including smelters and multiple hearth furnaces.

H-Iron: Competition for the Blast Furnace. P. M. Unterweiser. (*Iron Age*, 1956, **178**, July 12, 71–74). The principles and implications of the "H-Iron" process are described. This process efficiently reduces iron ore fines with hydrogen at relatively low temperatures and high pressures to produce metallic iron. Essential requirements are high grade ore (only oxygen is removed), and cheap fuel for production of heat and hydrogen. Cheap hydrogen can be produced by the Partial Oxidation Process from crude oil, natural gas, and other common fuels. The H-Iron process involves: drying and preheating the iron ore fines; reducing in hydrogen at high pressure and 900° F to fine iron powder; pressing the powder into a plate; breaking the plate into chips. The gas produced by the reaction is cooled to remove the water and the remaining hydrogen is recirculated. Tables summarize the performance of an open hearth and an electric arc furnace, using H-Iron as a substitute for all or part of the scrap charge. Most sizeable steel producers in U.S. are interested in the process.—D. L. C. P.

W. A. Charcoal Iron Production at Wundowie. J. S. Carr. (*Chem. Eng. Min. Rev.*, 1956, **48**, June 11, 263–269). Details are given of the Australian blast furnace plant and process with analyses of ore, flux, and iron. Details of fuel and fuel consumption, yields, by-product recovery, and economics.

PRODUCTION OF STEEL

The Influence of Steelmaking Practice on the Mechanical Properties of Steel. J. S. Vatchagandhy. (*Tisco*, 1956, **3,** July, 113–123). The author attempts to appraise the effect of steelmaking techniques on the mechanical properties. Acid and basic steels are compared and contrasted; the influence of nitrogen is discussed in some detail. The electric furnace, the duplex and the oxygen processes are dealt with fairly briefly as are the effects of ingot practice and the presence of tramp elements. (16 references).—L. E. W.

Oxygen in Iron and Steel Making. J. L. Harrison. (*Iron Coal Trades Rev.*, 1956, **173,** July 6, 15–24). The author reviews recent developments in the use of oxygen in blast furnaces, in the pre-refining of blast furnace iron, in lancing and flame enrichment in existing steelmaking processes, and in the development of new steelmaking processes such as the "L-D" process. Possible future trends are also outlined. Finally, oxygen developments in relation to capital and operating costs, and the effect of oxygen practice on present day operating costs are discussed.—G. F.

Lining of Converter in Donawitz Works. A. Wegscheider. (*Stahl u. Eisen*, 1956, **76,** May 17, 595–599). The lining of acid converters is discussed. The author gives the shortage of dolomite as the reason for early attempts using Austrian magnesite. Preliminary experiments were carried out in German Thomas works. Life tests were made on various types of cladding. Present lining technique with magnesite is described.

Co-operative Trials on All-Basic Furnace Roofs. The All-Basic Furnace Sub-Committee of B.I.S.R.A. and B.Ceram.R.A. (*J. Iron Steel Inst.*, 1957, **185,** Mar., 304–328). [This issue].

Control of Thomas Process by Temperature and Spectral Measurements. F. Wever, W. Koch, H. Knuppel, K. E. Mayer and G. Wiethoff. (*Engineer*, 1956, **201,** May 11, 483–484). A radiation pyrometer for taking temperature measurements, and a recording flame spectrometer for checking the course of the reaction, have been developed. The authors claim that one can maintain reliably the uniform composition of the metal by allowing the converter to be tilted in time and avoiding over-blowing.—M. D. J. B.

Development and Blowing Characteristics of a Model Basic Converter. W. A. Fischer and M. Wahlster. (*Arch. Eisenhüttenwesen*, 1956, **27,** Feb., 77–84). A description is given of the rebuilding of a 30 kg graphite bar furnace into an experimental basic converter. Lining and bottom life, conversion with oxygen-enriched air, and the advancement of dephosphorization (with reference to the effect on nitrogen uptake) are discussed. Comparison is made with melts from 2 and 25 metric ton converters.—A. C.

Dephosphorization of Basic Converter Steel. K. G. Speith and H. vom Ende. (*Stahl u. Eisen*, 1956, **76,** Mar. 22, 323–331). Dephosphorization by the addition of fine dephosphorizing agents is discussed. Temperature losses and after-blowing time are considered. Dephosphorization by after-blowing in the presence of residues remaining after the slag has been tapped off is referred to, and the interrelation of final phosphorus content, iron content in the slag, and temperature is indicated. The alteration in manganese and oxygen content on dephosphorization is alluded to. The authors describe a large-scale test on dephosphorization with premature slag tapping and subsequent after-blowing in the presence of slag residues. The economic angle is also discussed.—A. C.

Preparing Scrap for the Open Hearth. V. W. Jones. (*Steel*, 1956, **138,** June 18, 156–158). The new open-hearth scrap preparation yard erected at Middletown, O., for Armco Steel Corp., is described. Two crane runways handle 8300 net tons scrap per month. Arrangements for various types of scrap are indicated.—D. L. C. P.

The Utilisation of Manganese Ore in the Production of Open-Hearth Rimming Steel. J. Bečvář. (*Hutník*, 1956, **6,** (6), 172–175). [In Czech]. Experiments designed to study the possibility of replacing ferromanganese by manganese ore are described and evaluated. Optimum additions were determined, and the technological and economic advantages of the method are discussed.—P. F.

Production of Low-Sulphur Steel in the Basic Open-Hearth Furnace Using High-Sulphur Fuel. E. Zan. (*Radex-Rundschau*, 1956, Feb., 14–22). The principles of Grant and Chipman and the method of Robertson, Bacon and Till can be applied successfully.

The Use of Oxygen in Open-Hearth Furnaces. E. Bernard. (*Hutník*, 1956, **6,** (6), 168–171). [In Czech]. Optimum conditions for the use of oxygen are evaluated, and results obtained in experiments with various burners under varying operating conditions are given and their implications discussed.—P. F.

Tonnage Oxygen: B.O.C. Instal £1,000,000 Plant in South Wales. (*Iron Steel*, 1956, **29,** Sept., 429–431). The new tonnage oxygen plant at Margam, serving the works of Steel Co. of Wales Ltd., produces 100 tons of oxygen a day by the "Rescol" process. Details are given of the plant and the manufacturing process.—G. F.

Carbon Removal with Roof Mounted Oxygen Jets in Open Hearth Furnaces. J. E. Hood. (*J. Met.*, 1956, **8,** Apr., 418–419). The Steel Co. of Canada Ltd. has carried out a trial on one 250-ton O.H. furnace of the method of oxygen-lancing the bath by means of a lance through the roof, as developed by the Steel Co. of Wales Ltd. The equipment used is described, and the results show a saving in tap-to-tap time of 45 min, with an increase in production rate of 2½ tons/h.

Effect of Oxygen Enrichment on the Gradation of Particle Sizes in Effluent Gases from Thomas Converter and Electric Arc Furnaces. R. Meldau and D. Laufhütte. (*Arch. Eisenhüttenwesen*, 1956, **27,** Mar., 149–152). An attempt was made to determine, with greater accuracy than has been achieved heretofore, the sizes, number, and characteristics of particles in the brown fume from Thomas converters bottom blown with oxygen-enriched blast. The results are compared with others obtained in Germany and abroad, and differences are discussed. It is concluded that the apparent particle sizes for all methods of oxygen enrichment in Thomas converters and electric arc furnaces do not fall below 30 mμ, and that the problem of separating brown fume is mainly one of separating iron oxide.

Pre-refining in the Ladle, with Pure Oxygen, of Cast-Irons Very Rich in Silicon. P. Leroy and D. Menendez Magdalena. (*Inst. Hierro Acero*, 1956, **9,** May, 548–560. Special Number). [In Spanish]. A study of the effect of oxygen lancing liquid irons containing 2–3% silicon has been made with the aim of reducing the silicon content prior to charging into basic steelmaking furnaces. Data for 22 trials on 7–8 and 12–13 ton ladles is reported. With a single blowing period the large increase in temperature resulted in decarburization, and better results were obtained by stopping the blow and making a new, more basic slag which also helps in cooling the iron, then blowing for a second period. This technique uses 16 m³/t oxygen and eliminates about 1% silicon.—P. S.

Conveyor Helps in Cleaning Open Hearth Checkers. (*Iron Steel Eng.*, 1956, **33,** Jan., 170–73). This article describes a "hay loader" type of moveable conveyor used successfully in O.H. re-building operations.—M. D. J. B.

Russian Open-Hearth Furnaces. R. Sewell. (*Iron Steel*, 1956, **29,** Sept., 427–428). Data are given on current trends in Russian O.H. furnace design. Particular attention is given to the use of basic roofs and all-basic furnaces.—G. F.

Effect of Modernization on Efficiency: Case History of John Lysaght's Scunthorpe Works, Ltd. D. McQ. Potter. (*Iron Steel*, 1956, **29,** May, 183–187; June, 303–308). The reconstruction history of John Lysaght's Scunthorpe Works Ltd. is summarized, with details of the recent extensive modernization completed in 1953. The effect of these changes on the efficiency of the company is discussed from the viewpoints of: (1) throughput efficiency, expressed in terms of plant alignment, handling aids, balancing of output at each production stage, and time the material takes through all operations; (2) output per employee; (3) fuel efficiency.—G. F.

Basic Heated Air Cupola Furnace as Pre-melting Plant in Siemens-Martin Steelworks. W. Schüll and G. Rockrohr. (*Stahl u. Eisen*, 1956, **76,** Jan. 12, 1–13). After reference to the demand for increased raw steel production, the authors give grounds for the choice of the heated air cupola furnace for pre-melting. They describe the plant and its operation and discuss assembly problems. The composition of the pre-melt iron and its handling in the molten state are alluded to. Rise in output and a favourable influence on production costs are claimed, and prospects are reviewed.

The Allevard Ironworks. (*Aciers Fins Spéc. Franç.*, 1956, March, 102–106). A brief historical review is given of the Allevard Ironworks, which has specialized for very many years in the production of alloy steels. Special steel castings, magnet and spring steels are among its products, and within recent years a new shop has been established for the production of pure iron powder.—E. A. C.

The Use of Measuring Devices in Steelmaking. G. Husson and P. Leroy. (*Rev. Mét.*, 1956, **53**, July, 554–565). Control equipment and the instrumentation of open-hearth furnaces are briefly considered. Recent work carried out by IRSID on the measurement of temperature during basic Bessemer treatment in order to control the operation is reported. Methods of detecting the required end of blowing are also described.—B. G. B.

Instrumentation and Control in Steel Plants. J. R. Greene. (*Iron Steel Eng.*, 1956, **33**, March, 121–128). This article discusses the uses of instruments in steel plants and the characteristics required of control systems. The effects of instrumentation on both production and fuel economy are discussed.—M. D. J. B.

Methods of Estimating the Available Amount of Scrap in the Steel Industry. J. Dembowski. (*Hutnik*, 1955, **22**, (7/8), 253–258). Sources of scrap are classified in terms of the percentage available from casting and working processes and the rate of depreciation of steel equipment. Calculations are based on British Figures for the years 1949–1950.

Application and Development of Tonnage Oxygen in Steelmaking. R. E. Doré. (*Iron Coal Trades Rev.*, 1956, **173**, July 13, 105–107). The author outlines the advantages gained in the use of oxygen in the pre-treatment of iron, flame enrichment, oxygen lancing, and enrichment of the blast in the converter and in the blast furnace. The development of tonnage oxygen is briefly discussed.—G. F.

Oxygen Steelmaking in Canada. F. J. McMulkin. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 241–254). The top-blowing oxygen steelmaking process is in commercial production at the Dominion Foundries and Steel Ltd., Hamilton, Ontario. The author describes the preliminary pilot plant work and discusses the factors considered before the process was adopted. Details are then given of the new plant and the steelmaking unit, and the metallurgical control of the process is described.—G. F.

The Development of the Basic-Bessemer Process in Belgium and the Grand Duchy of Luxembourg. P. Coheur. (*Iron Coal Trades Rev.*, 1956, **172**, May 4, 555–557). The early development of the basic Bessemer process in Belgium and Luxemburg is reviewed and its present status in those countries is outlined. Special developments in blowing are discussed and the economic aspects are considered.—G. F.

Bessemer Steelmaking Process: Its History, Development, and Future. D. J. O. Brandt. (*Iron Coal Trades Rev.*, 1956, **172**, May 4, 547–554, 558). The author discusses Bessemer's discovery of the conversion process and its subsequent exploitation, and the development of the basic converter process, following the work of Thomas and Gilchrist. Modern Bessemer technology is considered, and the future expansion of the converter process is discussed.—G. F.

Causes of a Deterioration in the Properties of Bessemer Steel and some possible Preventive Methods. P. P. Arsent'ev, S. I. Filippov, and V. V. Yakovlev. (*Izvestiya Akademii Nauk SSSR, O.T.N.*, 1956, No. 2, 15–25). [In Russian]. The influence of impurities is manifested in various ways depending on the temperature range and the mode of testing the metal, and ageing, brittleness, and unsatisfactory weldability of mild Bessemer steel are caused by nitrogen, oxygen, and to some extent carbon dissolved in α-iron. Electron-microscopical investigations of the structure of metal with an increased content of impurity showed development of boundary zones and the possibility of phase segregation inside ferrite grains. The possible methods of improvement in production of converter steel are based on the application of top blowing of oxygen, additional vacuum treatment, and the neutralization of the influence of harmful impurities by appropriate alloying additions.—V. G.

Where Does the Nitrogen Come From. G. H. Enzian and R. Knox, jun. (*Metal Progress*, 1956, **69**, May, 102–109). The absorption of nitrogen by steel at elevated temperatures is briefly discussed.—B. G. B.

Methods for Determination of the End of Refining in the Basic Bessemer Process, Especially from Spoon Samples. J. Klärding and H. Rohr. (*Rev. Mét.*, 1956, **53**, Feb., 81–91). The flame emission and opacity and the noise are mentioned followed by observation of the fracture of a sample as a measure of phosphorus. A photographic method of examination of metal and slag is then given and illustrated.

Noise Measurements for the Inspection and Control of Converter Processes. J. Klärding. (*Metall*, 1955, **9**, Sept., 780–783); J. Klärding and F. R. Licht. (**10**, May, 405–415). Tracings of sound intensity are shown and correlated with the various phases of the blow.

The Thermal and Chemical Performance of a 90-ton Basic Open-Hearth Furnace. P. T. Carter, W. G. Cameron, and R. Hay. (*West Scotland Iron Steel Inst.*, 1956, Paper No. 489, April 13). Details are given of operational data obtained during a works test in which the thermal and chemical performance of a 90-ton fixed cold-metal basic open-hearth furnace was investigated over 12 consecutive heats. Chemical changes are discussed with particular reference to slag weight, iron, sulphur and silica balances, phosphorus and manganese, air oxidation during melting and refining, and slag viscosity. Data on thermal losses by water cooling, convection and radiation are presented and an approximate thermal balance is derived.—L. E. W.

Templeborough Melting Shop Reconstruction Scheme. F. Moore. (*J. Iron Steel Inst.*, 1957, **185**, Mar., 333–342). [This issue].

All-basic Furnace Construction and Operation at Keystone Steel and Wire Company. A. H. Sommer. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 84–93). The general open hearth facilities at Keystone Steel and Wire Co. are described, and details are given of the construction of the 170-ton all-basic furnace with flat suspended roof. Operating data from a 503-heat campaign are summarized and show that the furnace heat time is about 1 hour less than the shop average.—G. F.

Modified Slopes of Port Roofs. P. W. Nutting. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 95–97). Trials have been carried out at Inland Steel Co. with a flat port roof replacing the conventional sloping port roof in O.H. furnaces. The modified design improved production rate and fuel consumption but increased refractory wear.

Modified Slopes of Port Roofs. A. H. Sommer. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 97–101). Details are given of the port design of the all-basic O.H. furnace at Keystone Steel and Wire Co. in which the single-uptake port roof slopes downwards from the knuckle to the furnace end. The method of converting the three-uptake flat-roof design to the new design is outlined.—G. F.

Maintenance of Open Hearth Refractories by Gunning. W. T. Sergy. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 119–123). The author describes the development of a refractory gun technique for the maintenance of back walls, skewbacks, and uptakes in O.H. furnaces, and considers the possibility of roof maintenance by a similar technique. The use of the gun has reduced basic brick consumption, extended skew life, and increased furnace availability.—G. F.

Gunning Maintenance of Back Walls, Front Walls, Roofs, and Skews. R. M. Jordan. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 114–117). Hot-patching at the Lackawanna plant of Bethlehem Steel Co. is carried out by means of pneumatic guns, first applying a ready-mixed chrome refractory cement and then dolomite. Details of the practice are given and its benefits are outlined.—G. F.

Gun Maintenance of Back Walls, Skewbacks, and Roofs of Open Hearth Furnaces. W. R. McLain. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 117–118). The author discusses the practice of gun maintenance of O.H. furnaces at the South Works of United States Steel Corporation. The advantages of this method of maintenance are outlined, and brief details are given of the gun used.—G. F.

Gun Maintenance of Open Hearth Furnaces. R. E. Wright. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **28**, 128–129). A brief outline is given of the refractory gun maintenance procedure at Clairton Works of United States Steel Corporation, and the results obtained are surveyed.

Gunning Maintenance of Back Walls, Front Walls, Roofs and Skews. G. A. Grosvenor. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 124–127). The refractory gun is used in routine maintenance of O.H. furnaces at Colorado Fuel and Iron Corporation. The standard procedure is described, and experiments comparing refractory wear in similar furnaces with and without gun maintenance are discussed. Cost data are also given.—G. F.

Oxygen Sampler Guards Open-Hearth Efficiency. (*Steel*, 1956, **138**, Feb. 20, 116–119). A sampling system for measuring and controlling the oxygen content in open-hearth flue gases is described; it was developed by Leeds and Northrup Co.

The sample-probe tip is kept clean by a continuous spray of water; the sample passes through a steam ejector, condenser, and separator, to a paramagnetic oxygen analyser.—D. L. C. P.

Practical Importance of the Composition of Slag in Open Hearth Desulphurization. B. Matuschka. (*Rev. Mét.*, 1956, **53**, Mar., 203–214). In absence of reaction with gases, sulphur removal depends mainly on slag composition. Maximum sulphur uptake by slag depends upon lime content and metallic Fe and Mn and on the Mn in the slag exceeding the Fe. Studies on final S content of steel are then presented.

Systematic Study of Desulphurization. B. Marincek. (*Rev. Mét.*, 1956, **53**, Jan., 67–75). A schematic formulation of the reactions involved, with or without slag, is presented after discussion. Factors favouring the processes under various conditions are then given.

The Output from the Open Hearth Furnace. F. Bartu. (*Radex-Rundschau*, 1956, March, 47–59). Improvements are reviewed and future developments in checker design and the use of the Maerz-Boelens furnace profile are discussed. Heat balances for existing and ideal furnaces are given diagrammatically.

Operating Experience of Large All-Basic O.H. Furnaces. V. O. Kulikov, I. I. Bornatskiĭ, and A. P. Yargin. (*Stal'*, 1955, (9), 801–806). [In Russian]. Experience at the Kuznetsk works in the operation for five campaigns of 350-ton all-basic O.H. furnaces is analysed and compared with results for the same furnaces with dinas roofs. The use of basic roofs led to a reduction of 23·5% in the time for a heat, increases of 16·2% and 66·9% in the daily and campaign outputs, respectively, and to a reduction of 12·3% in the specific fuel-consumption (without hot standing). The main reason for stoppages for cold repairs of the basic-roof furnaces, was roof wear. In connection with the considerable influence on roof wear of cooling during bottom repairs and fettling, bottom life should be increased and repairs accelerated according to the practice developed at the Kuznetsk works, and the stability of the caisson linings should be increased by using high density, thermally stable magnesite-chromite brick; the practice of some works in supplying additional air round the perimeter of the gas port of the caisson could be adopted with advantage. Slag trap cleaning during a campaign leads to more uniform and economic operation of the furnace in the second half of the campaign. Forsterite bricks in the upper courses of the air packing of the regenerators of 350-ton furnaces when heated to 1450° C should be laid to a height of not less than 2·0–2·25 m. The forsterite brick cracks in service and is strongly contaminated with dust; the bricks disintegrate in reducing atmospheres and their use in the gas checkers has been discontinued.—S. K.

Basic Open-Hearth Steelmaking—Cold-Metal Practice. J. Gibson. (*West Scotland Iron Steel Inst.*, Advance Copy, Paper No. 486, Jan. 23, 1956). The physical factors affecting output—type of scrap, loading, charging, and furnace characteristics—are briefly considered and Scottish practice is exemplified by a description of Glengarnock works, at one time a hot-metal shop but for many years working entirely with cold metal. More detailed consideration is then given to metallurgical load, oxidation, and furnace design. Production data are also provided.—L. E. W.

Metallurgical Control in a Cold Metal Shop. C. A. Bigler. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 219–226). The author discusses the following main aspects of metallurgical control in cold-metal practice: (1) the control of melt-out carbon and factors influencing it; (2) the sources of sulphur in the O.H. furnace and the conditions necessary for rapid sulphur removal; (3) casting-pit practice, with particular reference to teeming rate and stripping schedule.

Factors Affecting Sand Usage and Delays in Production Due to Maintaining the Hearth in the Acid Open Hearth Furnace. J. W. Dougherty, Jr. and J. G. Bassett. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 72–80). The authors present some relationships between operating conditions and sand usage in the acid O.H. furnace, derived from data submitted by 9 works. Chemical and physical effects are considered separately, and the trends observed are presented in graphs. The main conclusion is that sand usage and delay time are increased by factors tending to produce more iron oxide or making it more available to react with the hearth.—G. F.

Maintaining Open Hearth Performance with Multiple Fuels. R. L. Sigl. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 12–21). The Armco Steel Corporation's development of an O.H. firing programme for varying proportions of different fuels is described, the fuel used being approximately 70% of a tar-oil blend and 30% of either natural gas or coke-oven gas. Details are given of the tar-oil blending, the burners used, firing schedules, and air control and regulation. Production data indicate that performance can be maintained with multiple fuels, no adverse effects being detected on production efficiency, or furnace availability. In addition, the plant fuel load balance is considerably eased.—G. F.

Mechanization of the Feeding of Deoxidizers to the Open-Hearth Furnace. V. I. Morozov. (*Stal'*, 1955, (9), 841–842). [In Russian]. Methods developed at the Magnitogorsk Metallurgical Combine for conveying deoxidizers to the O.H. furnace and for charging them into pouring ladles are described. The increased attention which the furnace crew could devote to other operations is said to have increased steel production.—S. K.

Thermal Work of an All-Basic O.H. Furnace. M. N. Starovich. (*Stal'*, 1955, (9), 791–801). [In Russian]. In this article experience in the operation of two basic-roof oil fired O.H. furnaces is analysed to provide the following preliminary conclusions on the use of all-basic furnaces. The maintenance of optimal thermal conditions during the charging, heating, and melting-down periods is the main factor for the high-productivity operation where greater thermal loads can be applied leading to hotter metal and to quicker reactions during the boil. With a chrome-magnesite roof it is essential to increase the thermal load on the bottom area in the thermo-technical periods of the process to 800×10^3 cal/m²h and decrease it continually during the boil to 300×10^3 cal/m²h at the end of this period. Improved fuel/air mixing in the furnace trough, greater flame kinetic energy, thermal insulation of the working space and the prevention of air-intake during the boil and at the end of the melting-down enable the thermal loads to be lowered during the second half of the process and the wear on roof and end-walls and the influx of dust into the regenerators to be decreased. Much can be gained by careful study of the thermal and metallurgical aspects of high-speed heats and the techniques used. Work on the development of all-basic furnace practice should aim at: (1) increased flame temperature and the regulation of its radiation and (2) improved combustion of oil to increase the thermal loads at the appropriate stages.

Devices for Investigating the Thermal Work of Metallurgical Furnaces. M. A. Glinkov and N. S. Vavilov. (*Zavodskaya Laboratoriya*, 1955, **21**, (10), 1203–1207). [In Russian]. Some water-calorimeter type of heat-flow meters are critically considered, with special reference to their use in steel-making furnaces. Details are given of instruments developed by the Moscow Steel Institute.—S. K.

On Methods of Investigating Heat Transfer. V. S. Kocho. (*Zavodskaya Laboratoriya*, 1955, **21**, (10), 1207–1213). [In Russian]. After a brief discussion of some instruments for measuring heat flow, the theory of their use in furnaces of the open-hearth type is considered in detail. Both stationary and non-stationary states, and heat flows to and from the bath are dealt with. The variation of these flows with height above the bath surface is studied. As a result of the investigations carried out, heat transfer can be controlled with greater precision. The use of heat flow data for improving furnace productivity and efficiency is indicated.—S. K.

Full Recovery of Chromium during the Melting of Chromium Steels in Basic Open Hearth Furnaces. T. Mazanek and W. Hansel. (*Hutnik*, 1955, **22**, (11), 405–408). The factors favouring chromium recovery are shown to be high temperature, small slag volume, low FeO content of slag, and a high Si content of the charge after melting down. During the melting of a charge containing 1% Si, 1% Mn, 2% CaO, and broken electrodes as a source of carbon, 80% Cr recovery was obtained at melt down, and 100% Cr and Mn recovery was obtained ½ h before tapping.—W. E. & A. P. M.

Atomization of Fuel Oil with High-pressure Gas. L. D. Yager. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 211–212). Laclede Steel Co. uses high-pressure (up to 210 lb/in²) natural gas as the atomizing medium in oil-fired O.H. furnaces. Operating details are briefly discussed and the advantages over steam-atomization are summarized.

Atomizing Fuel Oil with High-pressure Natural Gas. D. J. Murphy, Jr. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H.*

Comm., 1955, **38**, 212–213). Natural gas at 130 lb/in² is used to atomize fuel oil in one O.H. furnace at Scullin Steel Co., the remaining furnaces using compressed air. The advantages gained on this one furnace are summarized.—G. F.

High-pressure Natural Gas for Atomizing Fuel Oil. C. F. Henzelman. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 239–240). Preheated high-pressure natural gas is being used experimentally in place of steam as an oil-atomizing agent in one of the O.H. furnaces at Granite City Steel Co. The results obtained on three series of heats are summarized.—G. F.

Use of Large Amounts of Low-pressure Coke Oven Gas. F. R. Smith, Jr. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 237–239). The O.H. furnaces at Clairton steelworks are fired with a mixture of oil and low-pressure (6 lb/in²) coke-oven gas, one furnace being conventionally end-fired and eleven furnaces side-fired by burners in the sides of the ports, directing the gas into the combustion-air stream. The two systems and the firing schedule are discussed, and problems encountered are outlined.—G. F.

Atomization of Fuel Oil with High-pressure Gas. G. A. Grosvenor. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 213). Brief details are given of the performance of the first O.H. furnace at Colorado Fuel and Iron Corporation to be equipped with high-pressure natural gas atomization. The change has resulted in a production increase of 8–10%.—G. F.

Use of 100 Per Cent Natural Gas in Combustion of Open Hearth Furnaces. V. A. Agather. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 215–217). The O.H. furnaces at Piedras Negras, Mexico, are fired with 100% natural gas, with a low-pressure and a high-pressure burner at each end. The furnace design is outlined, and the advantages and disadvantages of the system are summarized.—G. F.

Controlled Firing Rates in the Open Hearth. F. J. Broglie. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 233–235). The author discusses the practice of controlling firing rates at the Sparrows Point plant, where mixed coke oven gas and oil are used. A typical firing schedule is given.

Statistical Evaluation of Open Hearth Production Factors. E. J. Sobey and R. E. Minto. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 175–179). The authors have used a multiple correlation method to evaluate the effects on O.H. production rate of four main factors: hot-metal temperature, charging time, total silicon charged, and amount of ore and hot-metal additions required. The results are shown in graphical form.—G. F.

Economics of the Acid Open Hearth Operation. R. M. Barnhart. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 66–69). The competition with basic steel makes the economics of acid open hearth practice of increasing importance. The author discusses the factors affecting the cost of an acid charge and considers the effects of some of the problems encountered in operation.—G. F.

Use of Chemicals to Remove Deposits in Open Hearth Checkers. E. B. Williams. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 227–232). The author describes the use of chemical agents (base material copper sodium chloride) for cleaning open hearth checkers. The nature of the checker deposits is discussed, and the operating practice and apparatus used for injecting the cleaning agent are outlined. The benefits derived are summarized.—G. F.

Residual Metals in Open Hearth Steel, 1954. J. D. Sullivan. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **8**, 130–134). From data submitted by 14 companies, the author surveys the current levels of residual elements in open hearth steels in 1954, and shows that they have increased only slightly in the past decade.—G. F.

Increased Steel Production from Desiliconized Hot Metal. E. C. Wright. (*Iron Steel Eng.*, 1956, **33**, Jan., 73–84). Analytical data presented in this paper shows that the use of desiliconized hot metal can increase production capacity at least 25% for present O.H. installations. Analysis also shows that a desiliconized metal with 2% carbon, 0·2% manganese, and 0·1% silicon can practically double electric furnace output and decrease power and electrode costs by 40 to 50%. The author suggests that both practices are applicable at integrated steelworks where ample hot metal is available. (7 references).—M. D. J. B.

Reaction Equilibria Between Molten Iron and Silica Saturated Slag. H. Schenck and G. Wiesner. (*Arch. Eisenhüttenwesen*, 1956, **27**, Jan., 1–11). After some words on the difference between conditions in the laboratory and in steelworks, the authors describe investigations of the effects of lime and alumina as additives to silica saturated slag. They discuss the reaction equilibrium between iron and slag, the saturation limit of slag, the equilibrium of the silicon and manganese reactions, and the conclusions that may be drawn for the deoxidation and melting processes in steelworks.—A. C.

Automatic Mechanism Saves Fuel on Furnaces. W. E. Boger. (*Blast Furn. Steel Plant*, 1956, **44**, July, 765–766). A new control system is described which has enabled the satisfactory use of by-product coke oven gas as a supplementary fuel with oil or tar for open hearth furnace operation.

Sulphur Pick-Up In Open Hearth Fired with Fuel Oils. B. Trentini, A. Peters, and G. Husson. (*Rev. Mét.*, 1956, **53**, July, 529–553). Sulphur pick-up from the fuel oil occurs during the melting period and ceases when the metal bath is entirely covered with a slag layer. The relationship between sulphur content of fuel oil and metal appears to be almost linear: an increase of 1% in the sulphur content of the fuel oil leads to an increase of 0·007% in the sulphur content of the steel in the conditions studied. It is considered that the partition of sulphur between slag and metal is very close to equilibrium.—B. G. B.

Duplex Process—An Expedient Method of Steel Making. N. R. Dutt. (*Sci. Eng.*, 1956, **9**, Aug., 10–14). A general elementary review of the process is given

Study of Basic Cupola Practice (III) Basic Cupola Acid Converter Duplex Process for the Production of Cast Steels. T. Tanaka, T. Maruo, and N. Hamano. (*J. Mech. Lab.*, 1956, **10**, Mar., 53–60). This is an account of trials in melting cast steel by the duplex practice using a basic cupola and an acid side-blown converter. In the basic cupola dephosphorizing operation the air blast seemed unfavourable. The converter operation was successful when blowing oxygen-enriched air into 2·0% silicon metals. Good quality metal, with 0·04% max. P, 0·012% max. S, and 0·006% N was produced by desulphurizing the scrap in the basic cupola, followed by blowing air with 30% oxygen into the acid converter.—J. G. W.

Jubilee of Héroult Electric Arc Process for Steel Manufacture. E Pakulla. (*Stahl u. Eisen*, 1956, **76**, Feb. 23, 221–222). 17 February, 1956, marked the 50th anniversary of the production of the first electric steel in a Héroult arc furnace in Germany. The historical contributions of the inventor Paul Héroult and the Richard Lindenberg firm are related.—A. C.

Technical Progress in the Construction of Electric Steel Making Furnaces in Germany. (*J. Four. Elect.*, 1955, **64**, Nov.-Dec., 204–210). An illustrated account of recent electric furnaces manufactured in Germany is presented.—B. G. B.

Oxygen Refining of Alloy Steels in the Basic Arc Furnace. R. Plessing. (*Radex Rundschau*, 1955, (7), Nov., 604–624). Chemical and physical processes occurring during oxygen injection are outlined on the basis of oxygen equilibria of various alloying elements. Particular attention is paid to high-chromium steels and the recovery of chromium from scrap.—E. C.

Electro Metallurgical Industry in France. (*J. Four. Elect.*, 1956, **65**, May-June, 100–101). A brief account of the steel works at Anciges in France is given. The plant manufactures special steels in electric furnaces. It is equipped with two 25-ton furnaces, one 12-ton furnace, one 4-ton furnace, and high-frequency furnaces. Output of the plant is 5000 tons per month.—B. G. B.

Fifty Years Progress in Arc Furnace Electrodes. F. B. O'Mara. (*Metal Progress*, 1956, **69**, Apr., 81–88). The development of carbon and graphite electrodes to their present state is discussed.—B. G. B.

Analysis of the Direct Current Arc. A. D. Harris and W. C. Gore. (*Welding J.*, 1956, **35**, March, 153s–160s). An analysis of the thermionic electric arc, based primarily on calorimetric data, is presented. Phenomena within the arc which are evaluated and discussed include the mechanism of power transfer to the anode, the formation and extent of the cathode region, the power dispersal in the arc, and the effect of cathode electrode variations upon the arc.—U. E.

An Up-to-date Comparison of Operating Costs of Open Hearth and Electric Furnaces in a Cold-metal Plant. J. E. Wilbanks. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 207–209). The Atlantic Steel Co. operates O.H. and electric furnaces of similar size and producing the

same steels by cold-metal practice. From data from a 6-month period, the author compares quality and costs of the charge, fuel, maintenance, and labour, and concludes that the electric furnace is the more economical.—G. F.

Comparison of Costs at Sheffield Steel. C. L. King. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 209–210). The Kansas City plant of Sheffield Steel Corporation operates five 130-ton O.H. furnaces working a hot-metal (cupola) charge and a 20 ft electric furnace using cold metal. A comparison of costs for 1953 and 1954 shows them becoming increasingly in favour of the electric furnace as experience of its operation is gained.—G. F.

Graphite Electrode Consumption in Electric-arc Furnaces. T. A. Cosh. (*J. Iron Steel Inst.*, 1957, **185**, Mar., 328–332). [This issue].

Arc Furnaces—Phenomenon of Flicker and the Distribution Network. M. D. F. Shankle. (*J. Four. Electrique*, 1955, **64**, May-June, 94–97). Translation of a communication to the American Power Conference 1953 from Westinghouse Electric. Effects of flicker and four methods of control are discussed.

Mechanisation of the Removal of the Lining in Arc Furnaces. N. I. Klimov and S. A. Vol'skiĭ. (*Stal'*, 1955, (9), 807–810). [In Russian]. After a description of the procedure adopted at the Dneprospetsstal' works for the manual removal of old linings during the repair of electric arc furnaces, an account is given of the mechanization of the various operations involved. The main part of the lining is extracted with the aid of a device which is moved and operated by the main and subsidiary hooks of the shop crane, and a special crane-operated shovel is used to remove the broken pieces. Bricklayers and furnacemen co-operate in the work of removing the old lining and placing the new refractory blocks in the furnace.—S. K.

Specifications for Mild Steels. J. K. Honeyman. (*Sheet Metal Ind.*, 1955, **32**, Nov., 855–859). The author shows that there are too many steel specifications by giving examples where the specifications are either unnecessary or are generally ignored. It is suggested that a specification should include only the factors related to the purposes in view, and this principle is applied in dealing with mechanical properties, analysis, tolerances, etc., with special reference to sheet and strip.—A. H. M.

Automatic Control of Continuous Casting of Steel in Russia. L. K. Tatochenko. (*Instrument Practice*, 1956, **10**, June, 518–519). A number of devices have been developed under the auspices of the Russian Central Research Institute of Ferrous Metallurgy, by which the level of liquid metal in the mould is indicated or maintained automatically by the use of gamma radiation. A gamma radiator and counter are located in opposite sides of the mould, and due to absorption of radiation by the metal, a strong signal is obtained only when the metal falls below the level of the counter. By fitting counters at different levels, a visual or aural signal can be installed for manual control, or a servo-mechanism for automatic level control. Various modifications of the principle are described.—L. D. H.

FOUNDRY PRACTICE

Foundry Expansion on East Rand. (*Engineer Foundryman*, 1956, **21**, July, 39–41). At the Benoni foundry of the Dunswart Iron and Steel Works Ltd., S. Africa, two 10 ton Demag and a 5 ton Birlec arc furnaces have recently been installed. They are described with special reference to the control gear.

The Principles of Modernisation in the Foundry. A. Bonneau. (*Fonderie*, 1956, Feb., 68–73). The modernization of two foundries, one making large castings, the other quantities of small castings, is described to illustrate the principles of modernization as applied to the foundry.—B. C. W.

Design of Foundry Buildings. E. O. Lissell. (*Gjuteriet*, 1956, **46**, (4), 53–57). [In Swedish]. Hints are given on the design of new, conventional-type sand moulding foundries. Sections deal with the optimum allocation of floor area to productive sections, size of bays in moulding section, layout of sand preparation area, core making and dressing sections, location of cupolas, storage space and choice of building materials.—G. G. K.

Shanks and Ladles. "Jaques." (*Found. Trade J.*, 1956, **100**, Jan. 12, 45–47). The problems involved in handling shanks of molten metal are briefly considered and a description is given of the construction of a one-man pouring ladle.

The Principal Factors which Affect the Life of Ingot Moulds. A. Herrero Prieto. (*Inst. Hierro Acero*, 1956, **9**, Jul., 823–830. Special Number). [In Spanish]. A brief review of the existing data on this subject is given together with the author's own observations at the Reinosa factory. It is concluded that (*a*) there is an optimum mould wall thickness, (*b*) the silicon content of the cast iron should be around 1%, (*c*) the ingot should have as short a stay as possible in the ingot mould, (*d*) the moulds should be heat-treated before use in order to prolong the mould life. The heat-treatment given to all ingot moulds at Reinosa is as follows: heat to 850° C, soak for at least 12 h and furnace cool. (22 references).—P. S.

The Efficiency of a Cupola. H. Jungbluth. (*Giesserei*, 1956, **43**, Apr. 12, 180–184). The thermal and metallurgical efficiencies are first described. The dependence of melting efficiency and iron temperature on the amount of coke per charge and on the combustion ratio is described. The influence of combustion losses on the economics of the process is discussed and numerical examples given. Finally the optimum economic and metallurgically favourable working conditions are presented graphically.—R. J. W.

Fundamental Considerations for Cupola Operation. W. R. Jaeschke. (*Found. Trade J.*, 1956, **101**, July 12, 39–45). The combustion of coke in a cupola is discussed together with some of the factors which affect the combustion and melting conditions. The importance of coke quality, burden characteristics and charge practice is emphasized. The air supply to the cupola and the use of cupola operating charts are briefly considered.—B. C. W.

On the Use of Dead Mild Steel Scrap in a Cupola of Medium Capacity. E. Ehrenstein Pollak. (*Inst. Hierro Acero*, 1956, **9**, May, 536–542. Special Number). [In Spanish]. The difficulties of satisfactory operation of a 53 cm dia. cupola employed intermittently for the production of small, mainly white iron castings are discussed. Trials were run using 20–30% soft iron scrap in the charge and the results are given; the wide variations in the quality of the coke and raw materials used has not allowed useful comparisons to be made.—P. S.

Cupola Experiments. K. G. Harris. (*Found. Trade J.*, 1956, **101**, July 26, 101–110). Experimental work in a 48 in. diameter cupola is reported. The variables examined include coke bed and charge distribution, optimum charge weights, lining erosion, the use of carbon and alumina bricks as lining materials, and water cooling. The experiments have enabled a considerable saving to be made in melting costs, and have also given considerable metallurgical improvements. The author considers that the use of water cooling in the form of rings imbedded in the brickwork, together with a carbon or alumina lining, should go a long way towards making continuous five day working a possibility.—B. C. W.

Ironfoundry Metal Melting Furnaces. F. Dunn. (*Iron Steel*, 1956, **29**, Sept., 433–436). The author examines briefly the uses of various types of furnaces for melting cast irons and indicates the developments which have taken place with each type during the past few years. He deals with cupolas, rotary furnaces, electric furnaces, air furnaces, and crucibles. Future ironfoundry melting practice is discussed. (67 references).—G. F.

The Rational Use of Fuel Oil in the Foundry. G. Almer. (*Fonderie*, 1956, Feb., 45–54). The combustion of fuel oil is briefly discussed and the various types of atomizing burners used for oil are described and compared. The application of oil firing to low temperature ovens and furnaces, annealing furnaces, crucible furnaces, and reverberatory furnaces is then discussed in detail.—B. C. W.

Report of Committee A-3 on Cast Iron. (*Amer. Soc. Test. Mat. Preprint No. 2*, 1956). This short report includes details of the revision of standard specifications for Grey Iron castings and Grey Iron castings for pressure-containing parts for temperatures up to 650° F.—B. G. B.

Heat Treatment of Gray Iron Castings to Develop Maximum Properties. C. R. Austin and W. W. Kerlin. (*Bull. School Mines Met. Univ. Missouri*, 1956, No. 91, 39–44). A general account of objectives and theoretical aspects with practical notes and discussion.

Notch Ductile High Strength Nodular Irons. G. A. Sandoz, H. F. Bishop and W. S. Pellini. (*Trans. Amer. Soc. Metals*, 1956, **48**, 971–985). Quasi-equilibrium mixtures of untransformed ferrite and austenite were prepared by reheating ferritized nodular iron to intercritical temperatures (1400–1550° F). After water quenching and tempering at 1200° F

an iron with high tensile strength and good notch ductility was obtained.—E. E. W.

The Influence of Several Elements on Spheroidal Graphite Formation in Cast Iron. J. Verelst and A. De Sy. (*Giesserei*, 1956, **43**, June 7, 305–315). The conditions under which the experiments were carried out are first described. The effect of aluminium, copper, bismuth and lead on the metallographic texture and mechanical properties was investigated. The separation of the alloying element in the texture of grey castings was attempted by (*a*) the electrolytic method and (*b*) by the use of different reagents. Deductions are made from the results in the light of the theory of graphite formation.

Chinese Research on Nodular Graphite Iron. (Chang Tso Mei and Chiu Sien Huer. (*Giessereitechn.*, 1956, **2**, Aug., 175). Results of experiments carried out since 1949 at the Chinese Institute of Metallurgy are reported. Instead of magnesium alloys, briquettes made of magnesium flakes, coke or pulverized graphite, with waterglass as a binder, have been used. Methods of refining castings alloyed with Ni–Mo, Ni–Cr, Ni–Cr–Mo and W have been investigated. Crank shafts have been made from a cast iron of low phosphorus content with a copper content between 0·5 and 0·8%. A process for the direct treatment of liquid pig iron of very low phosphorus content has been developed. Treatment is carried out at over 1400° C.—L. J. L.

A Note on the Subversive Influence of Titanium and Lead in Nodular Cast Iron. J. V. Dawson. (*Brit. C.I. Res. Assoc. J. Res. Dev.*, 1956, **6**, Apr., 180–183). It is shown that 0·1% titanium can be tolerated in the iron if no lead is present, but in the presence of 0·003% lead 0·1% titanium is completely damaging.—B. G. B.

Internal Chills in Moulds for Steel Castings. G. W. Miles. (*Found. Trade J.*, 1956, **101**, Aug. 9, 139–146). The problems involved in using either chaplets or internal chills in steel castings are discussed and some experimental results are presented to show the extent to which different sized inserts fuse into the casting. The results indicate that there is an optimum size of chill relative to the casting if fusion is to occur and if cracks and blowholes are to be avoided.—B. C. W.

Stainless Steel Casting. F. R. H. Allon. (*Canad. Metals*, 1956, **19**, July, 38). A short review of the types of stainless steel which are commercially cast is given.—B. G. B.

Foundry Sand Practice. A Review of Progress, 1939–1955. W. B. Parkes. (*Iron Steel*, 1956, **29**, July, 335–341). This review of foundry sand practice in the period 1936–1955 begins with accounts of the conditions in 1939 and of attempts to meet shortages of essential materials in the period 1939–1946. Processes which have been largely developed since 1946 are then described, with particular attention to shell moulding, the CO_2 process, and investment casting. New departures in conventional processes and in sand control are also discussed. (83 references)—G. F.

Thin-Section Work Involved in Radiator and Boiler Castings. E. Bremer. (*Foundry*, 1956, **84**, Apr., 112–117). Foundry practice at the Dunkirk Radiator Corp., Dunkirk, N.Y., is described.—B. C. W.

Scrap Investigation. J. McGrandle. (*Foundry Trade J.*, 1956, **101**, July 5, 5–16). A detailed discussion is given of the problem of investigating the production of scrap castings in a foundry. The aspects considered include the collection and sorting of data, the potential variables and their effects, the probability of obtaining a scrap casting, the imaginary and real variables, controls, and the difficulties of diagnosing the causes of a fault.

Foundry of M. B. John Ltd., Ballarat. B. S. Barham and H. J. Hassell. (*Inst. Brit. Found. Australian Branch, Convention* 1955, 89–105). Detailed descriptions are given of lay-out, and methods of maintenance and control are discussed.

Experimental Foundry Develops New Materials. (*Foundry*, 1956, **84**, July, 134–136, 138). A description is given of the facilities and the work of the experimental foundry at the new General Motors Technical Centre near Warren, Mich.

Crane Assists at Weigh In. (*Mech. Handling*, 1956, **43**, May, 310). The use of a Coles rail mounted crane working in conjunction with a Whiting weigh-car to make up cupola charges at the foundry of the Dodge Manufacturing Co., U.S.A., is briefly described.—D. H.

Modern Stationary Conveyors for the Foundry. A. Fackelmeyer. (*Giesserei*, 1956, **43**, Apr. 26, 221–224). A description is given of various types of conveyor for use in the modern foundry. Numerous examples of those which are available in Germany are illustrated and described. These include flat platform conveyors, moulding box and trough conveyors, drag-chains and circular conveyors. Also overhead, bucket, and chain conveyors and roller-ways are described.—R. J. W.

Improvements in the Method of Using Cupolas. J. Guillamon. (*Fonderie*, 1956, Jan., 21–27). The operation of a normal cupola with or without a fore-hearth is reviewed and a modified method of operating the former type is described. The method involves the use of a controlled draught through the bottom of the shaft to burn some of the coke below the tuyeres thus superheating the iron. Some results obtained with such a modified cupola are briefly presented and show that the percentage of satisfactory black-heart malleable castings obtained was increased using the new technique.

Melting Experiments on Cupolas with Basic Linings. F. Varga. (*Giessereitechn.*, 1956, **2**, Aug., 175). Magnesite, stabilized clinker dolomite, and corundum from Hungarian sources have been investigated to determine their suitability as basic lining for cupola furnaces. In an experimental furnace of 300 mm diameter, magnesite outlasted the dolomite clinker; but in an 800 mm diameter furnace the life of the dolomite was 1·37 times that of the magnesite.—L. J. L.

Conversion of Cupolas from Cold to Hot Blast and Operating Economies. R. Burleigh. (*Found. Trade J.*, 1956, **100**, Jan. 5, 5–10). The conversion of two 6 ton capacity cupolas to hot blast is described and the operating costs before and after conversion are compared. The saving on one year's running costs would be equivalent to the capital cost of the conversion. A method of water-cooling the melting zone of a cupola is described which enables the heat to be recovered for space or domestic water heating.—B. C. W.

Cupola Slagging Processes and the Water Cooled Cupola Shell. J. Chappel. (*Canad. Metals*, 1956, **19**, May, 50–56). A comparison is made of the advantages and disadvantages of rear and front slagging. The latter, which involves the slag flowing from the cupola with the metal and subsequent separation by a dam, is considered to have a number of advantages. The advantages of using a cupola with external cooling and no refractory in the stack are also explained.

Lining Cupolas With Carbon. G. B. Tatum. (*Foundry*, 1956, **84**, Jan., 184–186). The use and advantages of carbon bricks and carbon paste for lining cupolas are discussed and some practical experiences are briefly described.—B. C. W.

The Acid Lining of Cupolas. A. Bordes. (*Metalen*, 1956, **11**, Apr. 30, 175–181, May 15, 197–202). [In Dutch]. Collected data is presented in the article concerning the acid lining of 24 cupolas belonging to 21 undertakings working under various conditions including raw materials employed, patching and drying methods, lining wear, refractory consumption and cost per ton of melt. The information obtained in this investigation is to be used for further work proceeding on cupola linings.—F. R. H.

The Influence of the Hot Blast on the Chemical Processes in Cupola Furnaces. H. Jungbluth and K. Stockkamp. (*Giesserei*, 1956, **43**, Mar. 15, 129–136). The reactions which take place in cupolas are first described, followed by a description of the experimental technique. The following results are given and discussed: the effect of the hot blast on the combustion temperature of the coke and on the combustion ratio; the influence of blast temperature on the iron temperature, on the FeO content of the slag, and on the silicon and manganese contents of the cupola iron. Finally, the influence of the hot blast on the phosphorus and sulphur contents are described.

Operational Experience with Hot-blast Cupolas. R. Drechsler. (*Giessereitechn.*, 1956, **2**, Jan., 4–6). The conversion of two cold-blast cupolas to hot-blast operation by means of recuperators is described. Experience over several years has vindicated the success of this conversion.—L. J. L.

A Study of Melting Variables and of Refractory Linings in a Model Cupola of 10 cm Internal Diameter. B. Sochor. (*Reports of Czechoslovak Foundry Research, Appendix to Slévárenství*, 1956, **4**, (2). [In Czech]. Rammed acid linings were found superior to fire-clay. In the case of basic linings slag-attack was found to penetrate deeply, this not being so with acid linings. The high reactivity of the basic linings caused frequent troubles in the performance. The advantages of basic cupolas from the metallurgical point of view were confirmed, e.g. the sulphur content of iron made in the basic cupola is considerably below that of iron made in the acid cupola.—P. F.

Rotary Melting Furnaces. (*Metallurgia*, 1956, **54**, July, 29–30). A description is given of a 1 ton rotary furnace for melting cold charges for a shell moulding foundry. The furnace can be fired with a wide range of fuel oils or with creosote-pitch fuel.—B. G. B.

Mains Frequency Coreless Induction Melting Furnace. K. Scherzer. (*Metallurgia*, 1956, **53**, Apr., 171–174). The applications of this type of furnace are discussed. A large number of these furnaces have been supplied for the melting of cast iron. Compared with the high-frequency induction furnace the mains-frequency furnace represents a compromise between capital cost and production rate.—B. G. B.

Induction Melting Furnace at the Bofors Steel Works. T. Hahn. (*Mét. Constr. Mécan.*, 1956, **88**, Jan., 31–34). A description of a 12 ton high frequency furnace and of the associated electrical and mechanical equipment is given.—B. G. B.

The New Development of Channel-less Low Frequency Furnaces in European Foundries. O. Junker. (*Giesserei*, 1956, **43**, May 10, 236–240). The advantages and disadvantages of low frequency induction crucible furnaces from an electrical and also from economic and technical points of view are described and compared with low frequency induction ring furnaces and medium frequency crucible furnaces. Installations of various L.F. crucible furnaces in works, used for aluminium, magnesium, cast-iron and steel, are described, particular attention is given to the different construction characteristics for the different metals. Comment is made on the working life of these furnaces.—R. J. W.

White Irons—Part 1. Unalloyed and Low-Alloy White Irons. (*Bradley's Magazine*, 1955, (Winter), 8–10). White or chilled iron castings have been used extensively over the years, in crushing and grinding machinery of every type. Nowadays the low alloy white irons, containing nickel and chromium which enhance abrasion resistance and toughness, have almost completely superseded the unalloyed irons. The principal characteristics and basic metallurgy of these important alloys are summarized in this article.—M. A. K.

Latest Developments in Spheroidal-graphite Iron. W. W. Braidwood. (*Found. Trade J.*, 1956, **100**, May 17, 321–330). The advances which have taken place in the last three years in spheroidal-graphite iron are reviewed. A description is given of improved methods for adding metallic magnesium to the melt, including the use of sealed ladles and pressure chambers. The increased applications of S.G. iron are reviewed with examples drawn from many European countries.—B. C. W.

Processing of Pearlitic Malleable Iron. L. R. Jenkins. (*Foundry*, 1956, **84**, June, 112–115). A method for producing high-quality pearlitic malleable iron is described and the necessary melting, casting, and heat treatment controls are discussed. The importance of controlling the composition of the metal is stressed together with the advantages of carrying out the heat-treatment in a neutral atmosphere.—B. C. W.

United Pours the Big Ones. W. Molnar. (*United Effort*, 1956, **36**, (2), 7–9). Illustrations of the casting of a mill housing are shown.

Recent Developments in the Art of Precision Casting. N. J. Grant. (*Metal Progress*, 1956, **70**, Sept., 113–117). A review of precision investment casting in the U.S.A. is presented. Recent processes discussed include the Investment X, Shaw and Glascast. The former uses a disposable wax pattern while the two latter use a wood, plastic or metal pattern.

Fundamentals of Shell Moulding. P. H. R. B. Lemon. (*Found. Trade J.*, 1956, **101**, July 26, 113–115). The mechanism of bonding between the grains in the shell moulding process and the rheological properties of shell moulding resins are discussed in relation to the strength of the bond and the phenomenon of peel-back.—B. C. W.

Progress in Shell Molding and Shell Core. W. J. White, Jun. (*Bull. School Mines Met. Univ. Missouri*, 1956, No. 91, 15–24). A comprehensive review with discussion.

Oddride, Mechanised & Shell Moulding: Practice at Chamberlin & Hill, Ltd., Lichfield. (*Iron Steel*, 1956, **29**, Apr., 141–146, 152). A description is given of the layout and operation of the oddride, mechanized, and shell moulding bays, with brief details of other departments.—G. F.

Pinholing in Cast Iron and its Relationship to the Hydrogen Pick-Up from the Sand Mould. J. V. Dawson and L. W. L. Smith. (*Brit. C.I. Res. Assoc. J. Res. Dev.*, 1956, **6**, June, 226–248). Pinholing in grey irons is shown to be aggravated by the simultaneous presence of small amounts of Al and Ti. Coal dust and pitch in the moulding sand reduce the tendency to pinholing. Some limited correlation with hydrogen pick-up is shown.—B. G. B.

Surface Defects in Some Sand-Cast Stainless Steels. B. H. C. Waters, C. Hayward and H. F. Taylor. (*Found. Trade J.*, 1956, **101**, Aug. 2, 143–150). Experimental work designed to prevent the "measles" defect in 1% Ni, 11–14% Cr stainless steel alloys is described in detail. Results are given on the effects produced by casting temperature, skin-dried facing sands, shell moulding resin mixed in the facing sand, aluminium paint brushed or sprayed on as a mould dressing, and various organic and inorganic mould additions. An aluminium paint spray on the mould surface was found to be most successful in inhibiting measles formation and reducing or eliminating cold shuts. Works trials with this process are reported. A tentative theory is put forward to explain the measles defect and its prevention by an aluminium spray.

Hot Tearing. (*J. Inst. Brit. Found.*, 1956, **10**, Sept., 69–72). A review prepared by Technical Sub-committee T.S. 32 is given. (29 references).

Production Planning and Operations Control in a Steel Foundry. E. von der Horst. (*Stahl u. Eisen*, 1956, **76**, May 3, 552–557). A comprehensive review of the purposes, importance, organization and operation of planning and control is presented.

Records of Production and Defective Castings in Foundries. (*Gjuteriet*, 1956, **46**, May, 65–71). [In Swedish]. Based on discussions at a Swedish Foundrymen's Conference the article records the views expressed on the optimum layout of production and reject reports. A draft report is illustrated and described.—G. G. K.

Double Inspection Assures "Safe Service" Castings. (*Iron Age*, 1956, **178**, July 5, 67–69). Inspection of steel castings in a foundry handling a large variety of work is described. Magnetic particle tests are widely used to detect flaws.

Safety in the Iron Foundry. C. Gresty. (*Castings*, 1956, **2**, May, 20–21, 23, 25, 27; June, 20, 21, 23, 25–27). The problems of safety and health in iron foundries are discussed. The aspects covered include dust control and ventilation, eye protection, guards on plant and machinery, and screens in fettling shops.—B. C. W.

Dust Generation and Control in Foundries. W. H. White. (*Iron Steel*, 1956, **29**, Jan., 3–7). The author outlines the methods of sampling and estimating dust in foundries, and discusses the chief sources of dust which arise in the knocking-out and cleaning of castings. Recent improvements in ventilation and dust extraction are described, and general recommendations are given.—G. F.

VACUUM METALLURGY

The Application of Vacuum Technique to Certain Methods of Deposition and Fusion of Materials. R. P. Henry. (*Métaux-Corrosion-Indust.*, 1956, **31**, June, 274–288). Vacuum equipment for use on an industrial scale is described. The use of electron bombardment for the vacuum fusion of silicon ingots or materials for semiconductors is explained.—B. G. B.

Vacuum Melting: The Inside Story. S. A. Dawkins. (*Steel*, 1956, **138**, May 7, 100). The use of a mass spectrometer to analyse the gases drawn off from a vacuum furnace is described. The record is used to follow the process and determine the required end-point.—D. L. C. P.

REHEATING FURNACES AND SOAKING PITS

The Heating of Steel Ingots in a Rotating Hearth Furnace for Rolling Mills and Forges. R. Schubert and K. Guthmann. (*Stahl u. Eisen*, 1956, **76**, May 31, 700–703). The furnace is illustrated and the effects of hearth temperature and other internal thermal conditions are shown with comparisons with other types of furnace. Rate and internal details of heating of ingots depending on shape and size are also indicated.

Introduction to the Study of Reheating Furnaces. G. Grenier. (*Echo Mines*, 1955, May, 301–304; June 363–367; July, 458–461; Aug., 517–518; Sept., 583–585; Oct., 645–647; Nov., 717–720, 723; Dec., 781–783; 1956, Jan., 24–26; Feb., 79–81). A comprehensive account of various methods employed in the design of reheating furnaces is presented. Different fuels used are considered including oil, B.-F. gas, coke oven gas and pulverized coal. The type of heating cycles employed for normalizing are explained and the importance of accurate temperature control is stressed. The

designs of burners for gas-air mixtures are shown. Thermal efficiency is considered and radiation temperatures of flames and the processes of oxidation and decarburization for various types of steel are related to temperature and furnace conditions. Soaking pits are then considered with diagrams of sections and gas flow, gas compositions are tabulated and 1934 operating conditions are shown. Large size horizontal furnaces are then described with operating details, followed by continuous pusher-type furnaces, and the series concludes with a section on white annealing of sheets and strip.

Electrically Heated Soaking Pits. H. Langenbach. (*Stahl u. Eisen*, 1956, **76,** May 3, 614–618). Reasons are enumerated for considering an electric soaking pit in planning the extension of the soaking pit installation of an older German steelworks. The electric soaking pits in Oslo and Domnarfvet are described. Details of arrangement, space and current requirements, atmosphere control, consumption, and economics are discussed.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Recent Heat Treatment Furnace Installations. (*Metallurgia*, 1956, **53,** June, 257–275). An illustrated review is presented of a wide range of heat treatment equipment which has recently been installed. (50 illustrations).—B. G. B.

Automatic Furnace With Flexibility. R. C. Smith. (*Steel*, 1956, **138,** Mar. 19, 109–110). A two-row pusher type furnace is described which can carburize gears and give direct or press quenching as required. Automatic operation is provided and gears proceed to a wash and draw line.—D. L. C. P.

Works Processing of Stainless and Heat-Resisting Steels. R. Pospíšil. (*Hutník*, 1955, **5,** (10), 293–298). [In Czech]. Correct processing technology is described in detail.—P. F.

Scale Free Heating of Steel at 2200° F. W. Trinks. (*Indust. Heating*, 1956, **23,** April, 718–724, 730). Methods of heating steel to hot working temperatures without scaling are discussed.—A. D. H.

The Production of Protecting Atmospheres for the Heat-Treatment of Metals by the Partial Combustion of Coke-Oven Gases. J. Bělák. (*Hutník*, 1956, **6,** (6), 178–180). [In Czech]. Details of the construction of a full scale partial combustion, plant, and of the theoretical and experimental aspects of tests carried out are given. The protective atmospheres were used for processes in ferrous powder metallurgy.—P. F.

Induction Heating Handling Problem. D. W. Brown. (*Welding Metal Fab.*, 1956, **24,** June, 207–211; July, 256–261). The use of high-frequency induction heating for soldering, brazing, hardening and other engineering applications is discussed. Special attention is given to the mechanisms for obtaining linear motion for example, mechanical pneumatic or hydraulic rams, cams, solenoids and lead screws. Equipment is illustrated.–U. E.

Inhibition by Nitrogen of Graphitization in Steel. G. V. Smith and B. W. Royle. (*Trans. Amer. Soc. Metals*, 1956, **48,** 320–326). Cold-rolled, high carbon steel strip was prevented from graphitizing, during a heat-treatment known to cause it, by pre-heating in nitrogen for 6 h at 1900° F. The nitrogen content of the steel increased almost threefold. The effect of pre-treatment in hydrogen for two hours at 1900° F was to reduce the nitrogen and to increase graphitization.—E. E. W.

Mechanism of Surface Impregnation of Iron and Steel with Boron. G. V. Samsonov and N. Ya Tseitina. (*Fizika Metallov i Metallovedenie*, 1955, **1,** (2) 303–306). Armco iron and steel were treated with boron at 700–1200° C for various periods and the diffusion zones examined by micrographic, micro-hardness, and X-ray methods and the diffusion coefficients and energy of activation calculated. Change to γ-iron was observed with formation of carboboride. Mechanism is discussed.

On the Nature of Tempering in Brittle Steel. A. I. Rizol', L. G. Sakvarelidze and L. M. Utevskiĭ. (*Doklady Akad. Nauk SSSR.*, 1955, **105,** (2), 268–270). Mechanism is discussed in the light of electron micrographic and X-ray studies on various steels. (04KhG3, 15KhG3, 20KhG3, 04KhG3M etc.).

Contribution to the Study of the Cementation of Carbon Steel. T. Fărcaş, T. Golgotiu, G. Ailincăi, C. Ciochină and E. Andrei. (*Buletinul Institutului Politehnic din Jaşi*, 1955, **1,** New Series, 417–431). Trials with mixtures containing $CaCO_3$ showed that satisfactory results were obtainable with NaCl added. 13% $CaCO_3$, 7% NaCl and 80% C (wood charcoal) was used. This was equal to $BaCO_3$ or Na_2CO_3 mixtures.

Cementation of Carbon Steels of the Type (STAS 880–49) with a New Mixture Based on $CaCO_3$. T. Fărcaş, T. Golgotiu, G. Ailincăi, C. Ciochină and E. Andrei. (*Buletinul Institutului Politehnic din Jaşi*, 1955, **1,** New Series, 433–441). OLC 10 and OLC 12 steels were used. The mixture named in the previous abstract was successfully used at 870–900°. Thickness, structure and hardness before and after quenching were measured.

Cementation of Carbon Steels Using a New Mixture Based on Dolomite. T. Fărcaş, T. Golgotiu, G. Ailincăi, C. Ciochină, and E. Andrei. (*Buletinul Institutului Politehnic din Jaşi*, 1955, **1,** New Series, 443–460). Calcined dolomite was used as a substitute for barium or sodium carbonate for OL 34, OLC 10 and PLC 16 steels.

Rapid Gas Carburizing by Induction Heating. A. D. Assonov, K. Z. Shepelyakovskii and P. A. Lankin. (*Vestnik Mashinostroeniya*, 1954, **34,** (6), 56–60). Comparative tests of furnace-heated and induction heated pots are described, and gear carburizing in batch-type and continuous furnaces is given as an example. Carburizing is much accelerated, up to ten times, and immediate quenching can be carried out, or reheating can be performed where necessary. Automatic installations could be made.

Redistribution of Carbon on Surfaces of Sections of Heterogeneous Microvolumes of Steel during Tempering. S. F. Yun'ev and B. I. Bruk. (*Doklady Akad. Nauk SSSR.*, 1955, **104,** (4), 533–536). Diffusion of carbon to the surface is shown in micrographs and autoradiographic readings at temperatures between 450 and 700° and on unheated sections.

Continuous Furnace Cuts Small Part Hardening Costs. H. Chase. (*Iron Age*, 1956, **178,** July 26, 70–71). The use of an automatic carbonitriding furnace for casehardening small typewriter parts is described.—D. L. C. P.

The Calculation of the Kinetics of Hardening of Metallic Melts at Different Conditions of Temperature at their Surfaces. V. T. Borisov, B. Ya. Lyubov and D. E. Temkin. (*Doklady Akad. Nauk. SSSR.*, 1955, **104,** (2), 223–226). Mathematical.

Automatic Hard Surfacing Saves Pipe and Catalyst. R. F. Arnoldy. (*Welding J.*, 1956, **35,** Aug., 784–790). The use of manual and automatic hard surfacing applied to piping and valves belonging to the catalytic cracking unit of refinery equipment is described.—U. E.

Hard Facing the Catalyst Inlet Lift Bell in a Catalytic Cracking Plant in an Oil Refinery. (*Welder*, 1956, **25,** April-June, 28–30). The function of the catalytic cracking process is briefly considered and the application of hard facing to lining of the inlet bell is described.—U. E.

An Alloy Evaluation Test for Carburization Resistance. N. F. Spooner, J. M. Thomas and L. Thomassen. (*Amer. Soc. Test. Mat., Proceedings*, 1955, **55,** 793–796).

New Treatment of Ferrous Materials which must Resist Frictional Wear. E. Gonzalez Jolin. (*Inst. Hierro Acero*, 1956, **9,** July, 795–801. Special Number). [In Spanish]. A discussion of a sulphiding process is given, together with examples of the metallographic and other effects. The principal applications of the process are reviewed and examples are given.—P. S.

New Surfacing Techniques. K. H. Koopman and R. S. Zuchowski. (*Welding J.*, 1956, **35,** July, 665–671). The mechanized oxy-acetylene hard surfacing inert-arc processes, submerged-arc hard surfacing, and composite-tube-rod surfacing methods are described with illustrations.—U. E.

Some Effects of Metal Removal and Heat Treatment on the Surfaces of Hardened Steels. K. E. Beu and D. P. Koistinen. (*Trans. Amer. Soc. Metals*, 1956, **48,** 213–233). Retained austenite and residual stress measurements, using X-ray diffraction techniques, were used to study this subject. Decarburization was studied by means of austenite content, austenite and martensite lattice parameters and chemical carbon determinations with depth. The effectiveness of copper plating in protecting surfaces from decarburization is discussed.—E. E. W.

Thermal Chromizing of Molybdenum-rich Sintered Alloys. H. Bückle. (2 Plansee Seminar, "de Re Metallica", 1955. 239–244).

Note on the System Iron–Nitrogen. W. Pitsch and E. Houdremont. (*Arch. Eisenhüttenwesen*, 1956, **27,** Apr., 281–284). The nitriding of carbonyl iron in ammonia–hydrogen mixture is referred to. The use of micro-hardness

testing in the determination of nitrogen distribution in ferrite, the calculation of diffusion values, and saturation lines of ferrite for nitrogen (above 600° C), are discussed.

Mechanized Furnace Improves Heat Treatment of Grey Iron Castings. (*Indust. Heating*, 1956, **23**, Mar., 475–480). The operation of a mechanized gas fired furnace equipped with a cooling chamber for stress relieving and full annealing of grey iron castings is described.—A. D. H.

Mechanized Continuous Normalizing of Oil Well Tubing. (*Indust. Heating*, 1956, **23**, April, 771–774). Three gas-fired automatic furnaces each 4 ft long operated in tandem are used to normalize N-80 tube, 2⅜–2⅞ in. in diameter.

Austempering Shovel Blades. H. Chapman. (*Canad. Metals*, 1956, **19**, June, 46–50). The treatment of thin section carbon steel by this technique has been found to be very satisfactory for the production of shovel blades. Details of the manufacturing process are given.—B. G. B.

FORGING, STAMPING, DRAWING AND PRESSING

Eddy-Current Press Drives. F. L. Hopf and T. R. La Vallee. (*Trans. Amer. Inst. Elect. Eng., Part II. Applications and Industry*, 1955, **74**, 14–19). The design, characteristics, construction and applications of eddy-current press drives are described. Their advantages include no friction surfaces, vibration isolation and low maintenance, and draw speeds can be changed quickly to match the metal being processed. No increase in motor size is required.—L. D. H.

Steel Castings vs. Forgings. J. B. Caine. (*Bull. School Mines Met. Univ. Missouri*, 1956, No. 91, 45). (Abstract only).

Basic Forging Concepts. L. F. Spencer. (*Steel Processing*, 1956, **42**, June, 319–326, 350–351; July, 387–392, 418). In Part I the author deals briefly with the operation and basic products of hammers, upsetters and presses. A detailed discussion is then given of design considerations such as draft angles and parting line, effect of thin sections, problem of radii and fillets, effect of pockets, and the best utilization of flow lines. In Part II the suitability and application of a wide range of ferrous and non-ferrous alloys are discussed.—A. H. M.

Forging Presses use Ductile Iron for Brake Bands. (*Inco Nickel Topics*, 1956, **9**, (5), 9).

Are Stampings Giving You Trouble. F. Strasser. (*Iron Age*, 1956, **177**, Apr. 5, 108–11). Practical advice on the design of holes for stamping is given.—D. L. C. P.

Cutting and Shaping Tools for Finishing Small Numbers of Articles in the Stamping Shop. E. Vergen. (*Z. Metallkunde*, 1956, **47**, Apr., 217–220). Examples are given of the manufacture at low cost of cutting and shaping tools for small production runs; these may be useful in trial runs as a preliminary to series production.—L. D. H.

Steam Treatment Solves Tough Tooling Problem. (*Iron Age*, 1956, **177**, Apr. 5, 106–107). The problem was to cut keyway slots in heat treated cold rolled steel bars; high speed steel cutters only produced 4 parts each, chromed cutters 11 parts, carbide tools 14 parts. Steam treating the steel cutters for ½ hr at 1025° F allowed 125 parts per tool.—D. L. C. P.

Chemists Troubleshoot Shop's Metalworking Puzzlers. A. J. Zvarick. (*Iron Age*, 1956, **177**, Apr. 26. 106–107). The role of the chemist in metalworking shops is considered; he should be given the widest opportunity to be of value.—D. L. C. P.

Form the Product After it's Finished. F. Chatterton. (*Products Finishing*, 1956, **20**, Mar., 34–38). The finishing of steel sheet by roller coating and printing is described. It is possible to bend and stamp the material without damage to the coating.—A. D. H.

Low Cost Techniques Simplify Special Bends in Stampings. F. Strasser. (*Iron Age*. 1956, **177**, June 7, 124–126). Advice is given on the design of stampings involving bends in the metal. Lancing, louvering, and other bending operations are considered and suitable shapes and sizes for stamped parts are recommended with the aid of sketches.—D. L. C. P.

Drawing Processes in Sheet Working. E. Siebel and W. Panknin. (*Z. Metallkunde*, 1956, **47**, Apr., 207–212). Expressions are derived for the reactions and stresses occurring during deep drawing with punch and die. It is shown that higher drawing ratios are obtained when the strength of the bottom is increased compared with that of the flange of the work. The "Marform" and "Hydroform" processes and drawing with water or rubber dies are discussed from the point of view of achieving higher drawing ratios.—L. D. H.

How to Choose the Best Drawing Lubricant. E. L. H. Bastian. (*Iron Age*, 1956, **177**, June 14, 102–104). Lubricants used on the metal in press working and drawing are classified in 3 groups and selection for use on ferrous and non-ferrous metals is explained. The groups are: 'polar compounds'; 'polishing agents'; extreme pressure lubricants. A table summarizes recommendations.—D. L. C. P.

Modern Wire-Drawing Technology. F. Palíšek. (*Hutník*, 1955, **5**, (10), 305–308). [In Czech]. Several problems are suggested by the author for study in the Czechoslovak wire drawing industry, e.g. mechanical descaling of rolled wire, drawing at much increased speeds, etc.—P. F.

An Electrical Analogue for Estimating Temperature during Wire Drawing. A. E. Ranger. (*J. Iron Steel Inst.*, 1957, **185**, Mar., 383–388). [This issue].

Now, Tool Steel Extrusions. (*Steel*, 1956, **139**, July 9, 92). The types of tool steel extrusions made by Allegheny Ludlum Steel Corp., are explained. Compared with rolling, more intricate shapes are possible, and smaller quantities are economical, but there is a minimum size deperding on shape and steel composition.—D. L. C. P.

ROLLING-MILL PRACTICE

Single Stand Rolling Mills. G. Grenier. (*Echo Mines*, 1956, Sept., 515–517). An account of blooming and slabbing mills is presented. (6 references).

Progress at Velindre. (*Iron Steel*, 1956, **29**, Aug., 379–380). An account is given of the progress made at the Velindre cold reduction and tinplate plant, where production is now beginning. The layout of the plant is described and details are given of the operations carried out.—G. F.

More Strip for Tinplate. (*Anvil*, 1956, **4**, Autumn, 4–9). An illustrated description of the Velindre works.

Principles of a Metallurgically and Physically Balanced Hot Strip Mill. M. A. Leishman. (*Blast. Furn. Steel Plant*, 1956, **44**, June, 619–625). The author derives relationships which enable the optimum coil length and weights to be calculated for metallurgically balanced operation. A nomogram for calculating optimum coil lengths and weights for any combination of rolling conditions is given. The suggested method may also be used for calculations of optimum ingot size, number of slab reheating furnaces, the adjustment of mechanical and electrical equipment, and for planning for production and plant expansion.—B. G. B.

Rolling Mill Capacities and Rolling Histograms. A. Velsovský. (*Hutník*, 1956, **6**, (6), 175–178). [In Czech]. Theoretical considerations apertaining to rolling technology, concerned mainly with process efficiency, are discussed.—P. F.

Calculation of Technical Performance and Costing by Factor Analysis. K. Lehmann and H. Scholten. (*Stahl u. Eisen*, 1956, **76**, Apr. 5, 398–402). The method is described and applied to the example of a rolling mill.

Rolling Mill Speed Control. (*Elect. J.*, 1956, **157**, Oct. 12, 1122–1124). The electrical equipment and controls of the Velindre plant are described.

Mill Controls Toughen Steel Plate. J. P. Clair and G. Raynovich. (*Iron Age*, 1956, **177**, May 17, 104–106). An investigation is reported from Jones and Laughlin Steel Corp., which led to improved notch toughness of steel plate by adjustment of steel chemistry and mill practice. Slab thickness was altered to provide a more favourable relation between ingot/slab reduction ratio and slab/plate ratio; the nearer these ratios the closer are the longitudinal and transverse impact values. Also adopted were a restricted metal analysis and an optimum ratio of aluminium to sulphur in fully killed steel.—D. L. C. P.

More Strip from a Sendzimir. (*Steel*, 1956, **139**, July 16, 142). The use of 'Rycosol,' an oil-emulsion type combined coolant and lubricant, on a 16 in. Sendzimir strip mill is described. The high cooling rate allows big reductions at high speeds, without annealing between passes.—D. L. C. P.

Magnetic Amplifiers on a High Speed Accuracy Single Stand Reversing Cold Mill. A. L. Mogina. (*Blast Furn. Steel Plant*, 1956, **44**, June, 636–643). The control equipment on a 4 high reversing cold mill at the Midland works of the Crucible Steel Co., U.S.A. is described. The mill is capable of producing strip in 25,000 lb coils, 38 in. wide at a speed of 2000 ft/min.

Requirements of Modern Reversing Mills. (*Stahl u. Eisen*, 1956, **76**, Apr. 19, 443–468). I. **Mechanical Requirements on Breast Rolls.** H. Kohrn. Breast roll duty, the effect of the kinetic energy of the falling stock, dimensions, and installation

are considered. Experience with the newest reversing mills is reviewed. II. **Requirements on Pushers and Tilters as Indicated by Practical Experience.** W. Flender. Manipulators are discussed in general. The author deals with manipulating time, acceleration, constructional features favourable to reliability under overloading, and methods of dealing with various types of loading and disturbance. III. **Experience with Roller Tables on Modern Reversing Mills.** K. Boleg. Construction and dimensions, the effects of heat, splash lubrication, the drive casing, and a number of practical details of installation and maintenance are reviewed. IV. **Requirements on Ingot Tipping & Transporting Buggies.** W. Hennig. Fixed and mobile tippers are considered. The ratios of useful to total load obtained with two different types of transporting buggy are compared. Transit time, speed and acceleration, roadways, braking, vehicle weight, drive, bogies, rail tracks, and tipping arrangements are among the subjects discussed. V. **Service Experience with Synthetic Resin Moulded Bearings.** T. Tillmann. Service conditions and constructional methods are reviewed. Methods of lubrication, fire prevention, increase of life and decrease of friction losses are discussed. VI. **Electrical Installations for Reversing Mills, with Particular Reference to Automatic Control.** G. Nehlsen. Speed and accuracy, manual and programmed selection, and various types of control installation are discussed. VII. **Reactions from Rectifier or Converter Fed Reversing Mills.** K. Stahl. Load, control, switchgear and tests are described and discussed.

Preparation of Work and Production Planning to a Heavy Plate Rolling Mill. H. Friedrich. (*Stahl. u. Eisen*, 1956, **76,** May 19, 599–613). Organization and suitable forms are described.

MACHINERY FOR IRON AND STEEL PLANT

The Baling of Iron Scrap. A. Cowet. (*Rev. Gén. Méc.*, 1956, **40,** July-Aug., 289–292). An illustrated description is given of a plant for baling scrap iron and steel. The bales are 16 in. × 16 in. with variable length and the force used is between 72 and 120 tons.—B. G. B.

New Pump House Slakes Steel Mill Thirst. C. W. Granacher. (*Iron Age*, 1956, **178,** July 12, 84–85). Plant installed at Weirton Steel Co. for providing 184,000 gallons of water per minute from the Ohio River is described.—D. L. C. P.

Leakages from Compressed-Air Systems and their Determination. G. Hjerten, J. M. Rosenschiold and T. Rohloff. (*Jernkontorets Ann.*, 1956, **140,** (6), 425–450). [In Swedish]. On the basis of wide-scale measurements, leakages from compressed air systems in mines and steelworks are estimated at 18%. The theory of leakage is discussed in detail and an account is given of investigations into its nature and behaviour. Details are given of three methods of leakage measurement: the direct instrument, compressor unloading and the discharge method, the latter being especially recommended.

Telecommunication Equipment in Metal Works. K.-H. Saul. (*Stahl u. Eisen*, 1956, **76,** Apr. 19, 475–477). The design and approval of telecommunications equipment is considered. Details of antenna installation, fixed and mobile equipment, and the operation of a telecommunication service are discussed.

LUBRICATION

Silicone Lubricating Fluids and Greases. (*Machinery Lloyd*, 1956, **28,** July 21, 89–90).

Lubrication in Iron and Steelworks. H. Jones and G. D. Jordan. (*J. Iron Steel Inst.*, 1957, **185,** Mar., 389–408). [This issue].

Lubrication in a New Slabbing Mill and a New Wide-strip Mill. A. Diedrich and W. Niermann. (*Stahl u. Eisen*, 1956, **76,** Apr. 19, 469–474). A review of the construction and details of lubricating equipment on modern rolling mills is given and future progress is considered.

WELDING AND FLAME-CUTTING

Welding Technology Since 1950. H. J. Nichols. (*Canad. Metals*, 1956, **19,** Aug., 18–26). Recent developments in welding techniques are surveyed. These include: CO_2 shielded arc, inert gas metal arc and tungsten arc cutting, spot welding using an inert gas-shielded tungsten arc or consumable electrode, inert gas arc welding of pressure pipe, iron powder electrodes, arc-air gouging, automatic hard surfacing and semi-automatic arc welding.—B. G. B.

The Common Arc-Welding Processes. O. Becken. (*Z. Metallkunde*, 1956, **47,** July, 448–452). A review.

Arc-Welding Temperatures. R. J. Grosh, E. A. Trabant. (*Welding J.*, 1956, **35,** Aug. 396s–400s). This paper compares the results of two recent measurements of the quasistationary temperature distribution in thick and thin arc-welded stainless steel plates with an analytical study previously reported.

Ultrasonic Welding. J. B. Jones and J. J. Powers, Jun. (*Welding J.*, 1956, **35,** Aug., 761–766). The transducer-coupling system is described and the controlling parameters of power, vibratory energy exposure time, and static damping force are discussed. Both strength and deformation of the weld zone are compared with characteristic values incident to ordinary high pressure welding for certain metals.—U. E.

Transformation and Weldability of Low Alloy Steels. W. Hofmann and R. Müller. (*Schweissen u. Schneiden*, 1956, **8,** July, 237–240). Dilatometric measurements on model welded samples were made and the transformation in different types of material during heating and cooling was observed. Boreholes were made parallel and longitudinally to the weld seam for observing changes in length and temperature of the base material. Oscillograms were taken of changes occurring during welding at the side of the seam of Ck22, 20MnCr5 and 25 CrMo4 steels.—U. E.

Roof Passes in Stainless Steel with New Inert-Arc Procedures. E. B. Lavelle, L. H. Rasmussen and E. M. Kuchera. (*Welding J.*, 1956, **35,** July, 647–654). A new method of welding stainless steel piping is described. The fundamentals being: purging with argon, the joint is tacked securely at spacing slightly less than the diameter of the filler rod, filler rod is held down firmly into joint root and tangential to pipe at that point, the arc is concentrated on the end of filler rod, the arc is held as short as possible ($\frac{1}{32}$ in. best), and then traversed along the joint to form the root closure weld.—U. E.

Inert Gas-shielded Arc Welding. (*Automobile Eng.*, 1956, **46,** Sept., 356–359). An account of the British Oxygen Automatic Argonaut control system is discussed, with special reference to the welding of steel.

Electric Welding. Some Notes on Safety Aspects. H. W. Swann. (*Elect. J.*, 1956, **157,** Oct. 12, 1104–1108). Maintenance, earthing, and special aspects of the various welding processes are discussed.

Experiments on the Wedge Welding of Aluminium and Steel. W. Hofmann and G. Kornberger. (*Z. Metallkunde*, 1956, **47,** Feb., 87–89). Soft steel cones with a base diameter of 12 mm were driven into aluminium of 21 mm for welding tests. For satisfactory bonding it was necessary to apply a protective coating to the steel surface. The best results were obtained with a silver coating at 520 to 570° C, and a zinc coating at 410° C; copper coatings were not always satisfactory. Protective coatings were found to be unnecessary if protective gases, such as commercial nitrogen were used. Bonding takes place with the formation of a low-melting eutectic of the binary aluminium-coating metal system.—L. D. H.

Comparative Properties of Electrodes for Arc Welding Austenitic Manganese Steels. W. L. Lutes and H. F. Reid, Jun. (*Welding J.*, 1956, **35,** Aug., 776–783). Four basic types embracing seven grades of commercial materials recommended for fabrication or build up of a base for hard-surfacing overlays on austenitic manganese steel were tested and found to be less interchangeable than indicated by normal field usage. Best results were obtained with chromium-manganese or the composite nickel-manganese electrode.—U. E.

Lesson in Electrodes. (*Steel*, 1956, **139,** July 23, 86–88). Useful points from discussions between an electrode manufacturer and electric furnace crews are presented.—D. L. C. P.

Metal-Powder Electrodes and their Applications. E. Di Liberti. (*Welding J.*, 1956, **35,** Aug., 791–795). The relative operating qualities of iron powder electrodes and conventional electrodes are outlined and discussed.—U. E.

The Effects of Moisture in the Coating of Metal Arc Welding Electrodes. P. D. Blake. (*Welder*, 1956, **25,** April-June, 35–40). A review is given of literature dealing with hard zone cracking due to hydrogen in the deposited metal. The chemical reactions involved are briefly discussed.—U. E.

Effect of Notch Orientation on Weld-Metal Impact Properties. D. J. Snyder. (*Welding J.*, 1956, **35,** Aug., 381s–382s). Brief note on results obtained with **V**-notch Charpy-impact tests on weld metal deposited with E9015 electrodes.—U. E.

Carbon Dioxide for Welding. A. F. Knight. (*Canad. Metals*, 1956, **19,** June, 22–24; July, 24–27). The use of CO_2

as an inert shield during welding is discussed. Very good results have been obtained by this technique with normal and stainless steels which are comparable with the argon shielded process.—B. G. B.

Continuous Electric Resistance Welded Tube. W. G. Clewlow. (*Iron Steel*, 1956, **29,** Apr., 123–127). A description is given of the method of tube-making by the continuous electric resistance welding process. Some of the metallurgical factors of the process and properties of the product are discussed, and the advantages of the method are reviewed.

Austenitic Welds in 5% Cr–0·5% Mo Steel Pipes. H. G. Geerlings and W. P. Kerkhof. (*Brit. Welding J.*, 1956, **3,** Oct., 469–477). The advantages and disadvantages of the use of austenitic welding rods for welding 5% Cr–½% Mo steel pipes are discussed. The mechanical properties of the welds and the influence of service temperature are considered, special attention being given to the heat-affected zone between weld metal and parent metal. Results of stress calculations for heating cycles are given, taking into account the difference in coefficient of linear expansion between austenitic and ferritic steel.—U. E.

Welding Job Made Easier with Dual-Gas Setup. F. K. Mack. (*Iron Age*, 1956, **177,** May 3, 104–105). An instance is given of where it is advantageous to use argon for shielding the weld of one part of an assembly and carbon dioxide for another. Speed of welding, quality and economy accrue from using the former on the longitudinal seams of mild steel practice bombs, and the latter on the circumferential seams.

The Welding of Cr-Mo Low-Alloy Steels for Oil-Industry Equipment. F. F. Ates, L. Capel and C. P. M. Kijm. (*Brit. Welding J.*, 1956, **3,** Oct., 457–463). The motives for using low-alloy steels in the construction of equipment for the oil industry are discussed. A report is given on a laboratory investigation of various factors affecting the weldability, and on the criteria that have been applied.—U. E.

Welded Penstocks—Materials, Construction and Inspection. I. J. Ferris, M. G. Speedie and J. E. Bonwick. (*J. Inst. Eng. Australia*, 1956, **28,** June, 133–136). An account of a symposium. Choice of steel plate, brittle fracture, and inspection and X-ray and hydrostatic testing are considered.

Repair of Cast Iron Casings of a Diesel Engine. (*Prat. Sond.*, 1956, **10,** Aug.-Sept., 140–143). Steel was welded into the gaps produced.

Electrical and Metallurgical Characteristics of Mash Seam Welds. E. J. Funk, M. L. Begeman. (*Welding J.*, 1956, **35,** June, 265s–274s). An investigation is described in which a relationship between mash seam welding variables and resultant characteristics of the weld was determined. Recommended mash seam welding schedules are given.—U. E.

Testing of Welding for Warship Construction. W. R. Seward. (*Brit. Welding J.*, 1956, **3,** Oct., 442–447). The testing of welding at the Naval Construction Research Establishment, Dunfermline is discussed. Explosive methods of testing and results obtained from a number of C.T.S. and R.B.C. tests are considered.—U. E.

High Temperature Brazing. R. M. Evans. (*Batelle Tech. Rev.*, 1956, **5,** Aug., 8–12). A review of processes, problems, materials and uses. Brazing alloy compositions are indicated.

Silver Brazing. A. W. Swift. (*Product Eng.*, 1956, **27,** March, 135–141). Details are given of a number of silver brazing filler metals and also of different methods of brazing when using these metals. The design of joints is discussed, together with methods of heat treatment, finishing and inspection.

Brazing Furnaces Used for Fabrication of High Temperature Heat Transfer Apparatus. (*Indust. Heating*, 1956, **23,** April, 728–730). Furnaces used for brazing pinned heat transfer elements at 2000° F are described.—A. D. H.

Induction Brazing: Advantages Justify Costs. P. W. Morse. (*Iron Age*, 1956, **178,** July 5, 72–74). The characteristics of induction heating for soldering, brazing and welding are considered. Cost is often justified by selectivity, reliability, cleanliness, economy and speed of the process. Data for estimating the power required for heating are given.—D. L. C. P.

Fluxing Techniques. A. M. Setapen and E. S. Chamer. (*Steel*, 1956, **139,** July 9, 99–100). Ideas for applying flux to parts to be brazed are given, and good fluxing practice described.—D. L. C. P.

No-Heat Adhesives Simplify Joining Problems. (*Iron Age*, 1956, **178,** July 19, 118–119). Examples are given where epoxy-based adhesives have been invaluable in giving strong metal-to-metal joints.—D. L. C. P.

MACHINING AND MACHINABILITY

Machine Rough- and Finish-Grinds Castings Automatically W. G. Patton. (*Iron Age*, 1956, **178,** July 4, 78–79). The operation of an automatic grinder used for surface grinding and lapping pump bodies and covers is described. The sequence includes automatic transfer, gauging and wheel dressing, and flatness readings on the work of 0·0005 in. may be obtained.—D. L. C. P.

Machining Hard and Brittle Materials. R. C. Hall. (*Metal Progress*, 1956, **70,** Aug., 78–80). A short description of the electric spark machining technique is given together with details which enable the equipment to be constructed in a workshop.—B. G. B.

Metal Flow-turning. R. G. Longley and W. Hadley. (*Sheet Metal Ind.*, 1956, **33,** Aug., 519–529). In this comprehensive article the authors deal with the basic principles and advantages of flow-turning and give a description of a typical machine. Figures for speeds, feeds and pressures are listed for various ferrous and non-ferrous metals. Examples for the production of conical, cylindrical and irregular contours are discussed together with procedure and formulæ. One section reports experiments with special high-tensile, high-heat-resisting alloys, including titanium and nickel-base alloys as called for in jet-engine design.—A. H. M.

Effect of Heat Treatment on the Machineability of Case Hardening and Age Hardening Steels. F. Wever, H.-J. Wiester, W. Strassburg, H. Opitz and K.-H. Fröhlich. (*Arch. Eisenhüttenwesen*, 1956, **27,** Jun., 381–400). The cutting behaviour of variously heat-treated steels was examined in sustained turning tests. For long tool life, those structures were found favourable which had low strength and impact values. The best life with unalloyed and chrome-manganese case-hardening steels was obtained when in the uniformly coarse-grained ferritic lamellar pearlitic state. Non-uniform grain is no worse for turning than fine grain, but tool life is better with uniform coarse grain. The ferritic-pearlitic structure was found to be equally good for machining in chrome-nickel case-hardening steels, but good results were also obtained with annealed intermediate structures having small quantities of ferrite. Heat-treatable steels also have air-hardening characteristics conferring good machining properties. Best tool life was obtained in the soft annealed state. Surface finish was also investigated. Unalloyed and chrome-manganese case-hardening steels gave their best surfaces in the coarse-grained ferritic lamellar pearlitic state. Heat-treated structures gave surface finishes nearly as good as, or better than, fine-grained ferritic lamellar pearlitic structures. Soft annealed forms in all cases produced poorer surfaces than ferritic-pearlitic. Reasons were found to favour isothermal operation.

Modern Metal Cutting. G. V. Stabler. (*Trans. Inst. Eng. Ship. Scotland*, 1955–56, **99,** 324–344). Cutting action and chip flow are described with reference to tool materials and surface finish. Common errors in conception of machining are condemned.

Tool Life Increased with New Steel. J. Y. Riedel. (*Metal Progress*, 1956, **70,** Aug., 69–71). A new chromium–molybdenum tool steel has been developed with improved shock resistance and service life in both hot and cold work applications. The new steel is called Bearcat and has a nominal composition: 0·5% C, 0·7% Mn, 0·27% Si, 3·25% Cr, 1·4% Mo.—B. G. B.

Effect of Cutting Speed on Mechanical Properties of Chips Detached in Cutting Annealed Steel. M. Rosner, A. Simionescu and C. Ciochină. (*Buletinul Institutului Politehnic din Jași*, 1955, **1,** New Series, 403–416). Measurements of mean temperature are given and micrographs of surfaces. Thermo-electric measurements are made against a nickel bar. Except for a very thin layer of the tool surface, the temperature decreases with increasing speed. The findings are discussed and an explanation given.

The Effect of Cutting Conditions on Surface Quality from the Economic Point of View. H. Christoph. (*Schweissen u. Schneiden*, 1956, **8,** July, 230–237). Optimum conditions for flame cutting using low pressure acetylene, high pressure acetylene and propane are described. The instruments for measurement and test methods are explained. The following conditions were laid down: surface roughness 40–100 μ, smoothness 0·1 mm. groove $a <$ are sin $(0{\cdot}01 + 2/s)$ where s is the thickness of the plate. Diagrams are given for these conditions. Costs are compared.—U. E.

Cost in Metal Cutting. F. Akün. (*Instanbul Teknik Üniversitesi Bülteni*, 1956, **9**, 72–76). Calculations of most economic tool life are extended by evaluating increases in cost when other times and conditions are used.

CLEANING AND PICKLING

Metal Cleaning and Finishing Handbook. (*Iron Age*, 1956, **177**, June 28, 105–128). A series of tables presenting data for practical shop use include the following: spot test identifications of metal surfaces; phosphate surface treatments; chemical conversion coatings; metal conditioning (surface cleaning); typical electrolytic, immersion and spray cleaning operations; comparisons of pickling, degreasing, cleaning and descaling; properties and uses of chlorinated solvents; infra-red convection drying; typical organic coating properties; deburring and finishing; sizes of shot and grit; polishing wheel grit sizes; how to select power brushes; rust preventives, metallic coatings, specification plating; nickel electroplating baths.—D. L. C. P.

Cleaning by Means of Ionic Attack for Metallographic Observations with the Electron Microscope. E. L. Huguenin and M. Gauzit. (*Compt. Rend.*, 1955, **241**, 378–380). Three methods of treating specimens on the microscope immediately before observation are given. These are: ionic bombardment, the discharge tube method and pulverization in the discharge tube followed by bombardment.—G. E. D.

Reducing Degreasing Costs by Improved Handling. (*Electroplating Metal Finishing*, 1956, **9**, Mar., 82–84). The advantages of pneumatic hoists and of automatic totally enclosed degreasing machines are described.—A. D. H.

Pickling Processes Reviewed. D. J. Fishlock. (*Product Finishing*, 1955, **8**, Nov., 61–71, 110; Dec., 52–68, 104). A comprehensive review of pickling methods and equipment. Acid and other methods are described and the action of inhibitors and choice of rinsing processes are considered. Plastics, rubber and brick materials, acid recovery and effluent disposal methods are described.—A. D. H.

Pickling Processes Reviewed. 4-Treating Heat-Resistant and Corrosion-Resistant Metals. D. J. Fishlock. (*Product Finishing*, 1956, **9**, Feb., 84–97). The methods used to pickle alloy steels and nickel-base alloys are described. Safety precautions observed when hydrofluoric acid is used for pickling such alloys are discussed.—A. D. H.

Possibilities of Improving Steel Industry Pickling Processes by means of Polarisation Measurements. K. H. Brakstad. (*Jernkontorets Ann.*, 1956, **140**, (7), 512–519). [In Swedish]. After discussing variations occurring in the pickling process due to material properties, changes in temperature, etc. the author describes some measurements made of anodic and cathodic reduction when employing various inhibitors and pickling agents and discusses the manner in which the results differed from those obtained in practice. A Zero Resistance bridge was built to study the usefulness of polarization data in evaluating inhibitors.—G. G. K.

Automation in a Job Shop. E. A. Blount. (*Products Finishing*, 1956, **20**, Mar., 20–27). Semi-continuous processes for barrel finishing and barrel plating of pen and pencil clips etc. with nickel, gold or rhodium at the Spectranome Plating Co., New York, are described.—A. D. H.

Standardized Barrel Tumbling Pays Off. (*Iron Age*, 1956, **177**, June 21, 115–117). The employment of barrel tumbling on parts for automatic transmission assemblies at Chrysler Corp., is described. By careful control, close limits can be maintained on surface finish and edge and corner blending radii even with a limited choice of tumbling compounds and chips. A table gives examples of the process for 6 parts.

Electrolytic Polishing. A Summary of Present Practice. R. H. Warring. (*Elect. Rev.*, 1956, **159**, 10 Aug., 263–264). The principles and practice of electrolytic polishing are outlined; the advantages and disadvantages of the process compared with mechanical polishing are discussed and some details of current procedures are given.—L. D. H.

Spent Pickle Liquor Recovery. F. F. Jaray. (*Sheet Metal Ind.*, 1956, **33**, July, 482–483, 486). A description of the principles and method of operation of the Zahn system for the recovery of spent pickle liquor by the removal therefrom of iron sulphate in the form of monohydrate. Some operating details and costs of a German plant are included.—A. H. M.

PROTECTIVE COATINGS

Process Control in the Plating Shop. K. E. Langford. (*Electroplating Metal Finishing*, 1956, **9**, June, 177–182). Methods of control of temperature, current density, cathode movement, pH value and chemical analysis are reviewed and the interpretation of the results is discussed.—A. D. H.

Ten Ways to Check Deposit Thickness. (*Iron Age*, 1956, **177**, June 28, 130–134). The following methods of estimating plating-deposit thicknesses are described: microscope; measle chord; micrometer; induction; jet; spot; chemical strip; anodic solution; drop test; magnetic (N.B.S).—D. L. C. P.

Stress in Electrodeposited Coatings. J. B. Kushner. (*Metal Finishing*, 1956, **54**, Apr., 48–51; May, 58–63). A simple discussion of stress mechanisms is followed by the special applications to plated layers, with a review of theories and a note on methods of measurement.

Safety in Chrome, Nickel, and Cadmium Plating Shops. L. Lepage. (*Galvano*, 1956, **25**, Jan., 27–28, 43; March, 37–40). Construction, electrical installations and ventilation are considered and then toxic hazards in the various operations and general hygiene.

Treatment of Plating Shop Effluent. J. Lakin. (*Electroplating Metal Finishing*, 1956, **9**, July, 221–224). The author describes plant installed at Mullard Radio Valve Works, Waddon, for the treatment of effluent containing cyanide and chromium.—A. D. H.

Discharge of Finishing Trade Effluents to Sewers: The Legal Position. Lord Meston, (*Product Finishing*, 1956, **9**, June, 58–61). The statutory position both in and outside London concerning the discharge of trade effluent is reviewed.—A. D. H.

Covering Power in Chromium Plating Baths. R. H. Rousselot. (*Metal Finishing*, 1956, **54**, Aug., 60–65). Seven factors breaking down into five independent variables are defined and interdependence of temperature and mean current density is discussed. A method of determining minimum plating time is given. An appendix discusses the empirical nature of the chromate-to-sulphate rule.

On the Properties of Electrolytic Nickel Coatings. L. A. Rubio Felipe. (*Inst. Hierro Acero*, 1956, **9**, Apr.-June., 679–685). [In Spanish]. A study has been made of the hardnesses and microstructures of nickel plate, electrolytically deposited from a series of one chloride and six sulphate type baths for a variety of plating conditions. The results indicate that the mechanical properties are determined by the quantity, state, and nature of the impurities in the deposit. The microstructure is influenced by the bath composition and pH value; the Watts bath produced large, columnar crystals, the bright plating baths produced the finest crystals in a distinct layered structure.—P. S.

Electrodeposition of Nickel from Fluoborate Solutions. (*Galvano*, 1955, **24**, Dec., 26–28; 1956, **25**, Jan., 23–26; Feb., 31–32; Mar., 33–36). The process has been studied over a wide range of concentrations, temperature, pH, and stirring conditions. Chloride and boric acid are advantageous, and a wetting agent is advisable. Comparison was made with other bath compositions and current densities and yields are given. Other additives were found to give bright coatings. Impact and Knoop tests on the products are recorded.

Determination of Sodium Formate in Organic-Type Bright Nickel Solutions. K. E. Langford. (*Electroplating Metal Finishing*, 1956, **9**, Sept., 293). A modification of the alkaline-permanganate method is given. After removal of nickel, the interfering organic materials are eliminated by activated charcoal.—A. D. H.

Advanced Techniques for Tight Coating of Zinc. N. E. Cook. (*Indust. Heating*, 1956, **23**, Feb., 312–318, 344). The operation of the Cook–Norteman process at the works of the Wheeling Steel Corporation is described. Adherence of coating is achieved by suppression of the formation of the iron–zinc alloy layer by the addition of aluminium to the molten zinc.—A. D. H.

Automatic Plant for Zinc Plating Radio and Television Components. W. Kissel. (*Electroplating Metal Finishing*, 1956, **9**, Sept., 297). A large German plant is described.

Attack by Molten Iron-saturated Zinc on Iron Containing Aluminium. D. Horstmann. (*Arch. Eisenhüttenwesen*, 1956, **27**, Mar., 161–163). The attack was found to be up to about 1% greater with a small aluminium content. For larger amounts of aluminium (about 5%) the attack was found to be less than in the case of soft iron without aluminium. The

temperature range in which the zinc attack proceeds linearly with time is extended very slightly at the low-temperature end when aluminium is present.

Electrolytic Recovery of Zinc from Galvanizer's Sal Skimmings. P. M. Sullivan. (*U.S. Bur. Min. Rep. Invest.* 5205, 1956, Mar.). The successful application of an electroamalgam process for recovering zinc as refined metal from galvanizers' sal skimmings is described. (37 references).

Oxidation of Carbide Alloys for High-Temperature Purposes. J. Hinnüber, O. Rüdiger and W. Kinna. (*Arch. Eisenhüttenwesen*, 1956, **27,** Apr., 259–267). The effects of adding tungsten, chromium, or tantalum-niobium carbides are described with particular reference to the rate of oxidation and the formation of oxide layers in annealed specimens of titanium carbide-cobalt alloys. The significance of the test results is discussed in the light of fundamental physical considerations.

Phosphate Coatings fight Marine Corrosion. (*Indust. Finishing*, 1956, **9,** Jan. 316–318). An account is given of the Jenolizing process for rust removal and surface conditioning for repainting.

Temporary Protective Coatings. 3.-Hot Dip Compositions. E. Strong. (*Product Finishing*, 1956, **9,** April, 71–79). The properties of plasticized ethyl cellulose and waxes as temporary protection for fragile articles are presented and discussed.

Report of Committee C-22 on Porcelain Enamel. (*Amer. Soc. Test. Mat. Preprint No.* 31, 1956). Details are given of a tentative method for testing the resistance to thermal shock of porcelain-enameled utensils.—B. G. B.

Tests to Determine the Adhesion and Brittleness of the Vitreous Enamel Coatings on Cast Iron and Sheet Steel. P. Tyvaert. (*Fonderie*, 1956, May, 185–197). Three tests for determining the adherence and brittleness of vitreous enamel coatings are described in detail and some results obtained with coatings on cast or sheet specimens are presented. In the first test a steel ball is repeatedly driven against the specimen by a falling weight and the number of blows to give cracking and spalling are recorded. In the second test a steel ball and weight are dropped from increasing heights on different parts of the specimen until failure occurs when the minimum height to give cracking or spalling is noted. In the third test the specimen is held vertically and struck by a weighted pendulum with increasing kinetic energy. In this test the brittleness of the coating is taken as the minimum energy required for cracking and the adherence is judged by the state of the coating after it has received a series of impacts.—B. C. W.

A Dilatometric Study of Specimens from Cast Irons Used for the Manufacture of Enamelled Ware. P. Détrez. (*Fonderie*, 1956, Apr., 151–156). The temperature at which graphitization commenced and the transition temperatures on heating and cooling were determined dilatometrically for a number of cast irons used in the production of enamelled ware. The results are discussed in relation to the effects of silicon and manganese on the graphitization and transition temperatures, and to enamelling practice.—B. C. W.

Proposed Method of Test for Determining Sag Resistance of Steel Sheets for Porcelain Enamelling. A.S.T.M. Committee C-22. (*Amer. Soc. Test. Mat. Proceedings*, 1955, **55,** 431–433).

Solution Ceramics. T. A. Dickinson. (*Metal Finishing J.*, 1956, **2,** May, 145–150). Solutions of nitrates of Cr, Al, Ce, Co, Ni, Zn and La in various mixtures were applied by spraying to mild steel surfaces preheated to 260°–315° C to produce coloured coatings. Ammonium zirconyl carbonates and ammonium chromate, vanadate and molybdate solutions were also investigated. Apart from the decorative value of the coatings, it is considered that they may be suitable as primer coatings for flame sprayed ceramic finishes.—A. D. H.

Frame Sprayed Refractory Coatings on Metals. T. A. Dickinson. (*Metal Finishing J.*, 1956, **2,** Mar.-April, 89–90, 102). A brief account is given of the Ryan process for applying heat resistant ceramic coatings by spraying a metal surface with refractory particles from a modified metal spray gun.

Painting of Steel Structures in Industrial Atmospheres. V. Tolvanen. (*Tek. Kemian Aikakausilehti*, 1956, **13,** Mar. 15, 139–140, 143–144, 147; Sept. 15, 470, 473–474, 476). [English Summary]. Anti-corrosion pigments are reviewed and classified and pre-treatment discussed. Vehicles, succession of coats, choice of paint systems and maintenance and inspection are considered in the second part.

Paint-Zinc Combinations for Corrosion Protection of Iron and Steel. E. E. Halls. (*Electroplating Metal Finishing*, 1956, **9,** June, 187). Results of outdoor exposure tests on mild steel specimens protected by painting over sprayed zinc or galvanized coatings are presented. The sprayed specimens were generally superior to the galvanized sheets. (See Ibid, 1954, **7,** July, 279–284; Aug., 315–321).—A. D. H.

The Painting of Castings. E. Johnson. (*Electroplating Metal Finishing*, 1956, **9,** July, 225–228). Methods of priming, filling and finish painting castings are explained.—A. D. H.

Contribution of Laboratory Work to the Study of Anti Rust Paints. M. Tarbouriech. (*Peintures-Pigments-Vernis*, 1956, **32,** June, 506–514). The study of this type of paint by the natural deterioration in service and by accelerated test procedures are discussed. The efficacy of different pigments and media has been studied and the results obtained are presented in graphical and tabular form.—B. G. B.

S.S.P.C. Paint System Used on Harahan Bridge. (*Steel Structures, Painting Bulletin*, 1956, **2,** Summer, 1). A system of surface preparation followed by three coats (red lead, carbon black, and aluminium) was used.

POWDER METALLURGY

Powder Metallurgy. J. F. C. Morden. (*Metal Ind.*, 1956, **89,** Aug. 17, 123–126; Aug. 24, 146–147). Particle size and shape and their determination, porosity and microstructure and surface conditions are briefly considered.

Powder Metallurgy—Now (New Techniques, Improved Properties, Wider Use). F. V. Lenel. (*Amer. Soc. Test. Mat., Proceedings* 1955, 655–688). The Gillett Memorial Lecture.

Report of Committee B-9 on Metal Powders and Metal Powder Products. (*Amer. Soc. Test. Mat. Preprint. No.* 15, 1956). Draft specifications for high, low and medium density iron structural parts, green strength of compacted metal powder specimens and density of cemented carbide are proposed.—B. G. B.

Heat- and Corrosion-resisting Sintered Materials. Arc-Melted versus Powder Metallurgy Titanium Carbide. I. Cadoff, J. P. Nielsen and E. Miller. (*2 Plansee Seminar "de Re Metallica"* 1955. (50–55). Effects on defect lattices of additional carbon and oxygen are discussed. **Sintered High-Temperature Materials.** P. Schwarzkopf. (199–204). **Sintered Materials for High Vacuum Uses.** M. Auwärter. (216–222). **Increasing the Heat-resistance of Alloys by Internal Oxidation.** J. L. Meijering. (405–410). **Metallic Sintered Materials with Synthetic Intergranular Substance.** R. Mitsche. (411–426). Iron-aluminium alloy was used with carbonyl iron powder with or without Al_2O_3. **A Technical Sinter Diagram.** G. Ritzau. (442–456). A method of following changes during sintering is described with curves for iron and other metals. **Powder Ceramics—Powder Metallurgy: A Review of Relationship and Developments.** M. A. Schwartz. (457–464). Tests and fields of usefulness are briefly discussed.

Metal Powder Rolling—a New Fabrication Technique. S. Storchheim. (*Metal Progress*, 1956, **70,** Sept., 120–126). The manufacture of metal in sheet form from powder is described. Results obtained with 18–8 stainless steel powder are discussed and show the advantages and potentialities of the techniques.—B. G. B.

New Developments in Powder Metallurgy for Materials Resistant to High Temperatures. R. Meyer. (*Métaux-Corrosion–Indust.*, 1956, **31,** May, 219–232). A detailed review of recent work on this subject is presented. A general account of the types of high temperature materials developed by powder metallurgical techniques is first given and then details of the properties of some of the most successful materials are described. (33 references).—B. G. B.

FERRITES, CERMETS AND CARBIDES

Studies on Ferrites VI. Microstructures of Mn–Zn and Cu–Zn Ferrites Containing As_2O_3 Bi_2O_3, Sb_2O_3 and SnO_2. T. Takei and M. Sugimoto. (*Rep. Sci. Res. Inst.*, 1955, **31,** Nov., 372–376). [English Summary]. Up to 3% by weight of the oxides solid solutions are formed, with higher proportions cavities form, but crystal size is unchanged except slightly by small (0·1–0·3%) additions.

Neutron Diffraction Observation of Heat Treatment in Cobalt Ferrite. E. Prince. (*Phys. Rev.*, 1956, **102,** May 1, 674–676). Heat-treatment in a magnetic field is studied. Displacement of magnetic moments from the directions expected from crystalline anisotropy alone is observed, and is greater in iron-rich than in stoichiometric ferrites.

An Antiferromagnetic Transition in Zinc Ferrite. J. M. Hastings and L. M. Corliss. (*Phys. Rev.*, 1956, **102,** June 15, 1460–1463). Neutron powder-diffraction patterns have been obtained for zinc ferrite over the range 2·7° K to 300° K. The data indicate that a transition takes place at about 9° K from paramagnetic to antiferromagnetic. A model is proposed and discussed.—E. E. W.

The Free Energy of Formation of Zinc Ferrite. I. G. F. Gilbert and J. A. Kitchener. (*J. Chem. Soc.*, 1956, Oct., 3924–3926).

Ferrites in Waveguides. G. H. B. Thompson. (*J. Brit. Inst. Radio Eng.*, 1956, **16,** June, 311–328). The gyromagnetic mechanism controlling the permeability of a ferrite at microwave frequencies is investigated theoretically, and the theory is applied to circular waveguides containing a ferrite magnetized along the axis, and to the effect of transverse magnetization of the ferrite. Application of the effects to the construction of isolators and circulators are described, their relative merits discussed and methods of calculation of their characteristics indicated.—L. D. H.

Growth of Single Crystal Rare Earth Orthoferrites and Related Compounds. J. P. Remeika. (*J. Amer. Chem. Soc.*, 1956, **78,** Sept., 4259–4260).

On the Processes Occurring on Sintering Carbides in the Presence of a Liquid Phase. B. Čech. (*Hutnické Listy*, 1956, **11,** (7), 419–424). [In Czech]. Sintering tests on the systems WC–Co and Cr_3C_2–Ni are described, and the X-ray and micrographic data discussed. Crystallites were found to form in the binder phase on solidification. Certain current views concerning the structure of sintered carbides are shown to be irreconcilable with the experimental evidence obtained by the author.—P. F.

Heat- and Corrosion-resisting Sintered Materials. (2. *Plansee Seminar* "*de Re Metallica*" 1955). **Interactions in Mixtures of Hard Materials at Very High Temperatures.** G. A. Geach and F. O. Jones. (80–91). **Some Properties of Recently Developed Hard Metal Produced by Infiltration.** C. G. Goetzel and L. P. Skolnick. (92–98). Titanium carbide in tool steel matrices is described. **The Role of Binder Phase in Cemented Carbides.** J. Gurland and J. T. Norton. (99–110). A theory of the strength of sintered carbides is outlined. **Titanium-Carbide Base Cermets.** W. L. Havekotte. (111–129). **Contribution to the Study of the Ternary System TiC-ZrC-WC.** F. Tombrel. (205–215). **High-temperature Materials and Methods of Evaluation.** W. B. Grandall and J. R. Tinklepaugh. (344–360). In the second section a programme of cermet research is given. **Sintering Properties, Microstructure and Properties of Cr–Al_2O_3 Cermets.** E. M. Onitsch-Modl. (427–441).

PROPERTIES AND TESTS

Fundamentals of Physical Metallurgy. T. Fullwood. (*J. Inst. Prod. Eng.*, 1956, **35,** Oct., 634–639). A lecture on elementary crystal structure and the iron-carbon diagram is reported.

Influence of Mechanical Treatment on the Properties of Steel. P. K. Chakravarty. (*Tisco*, 1956, **3,** July, 124–134). The author discusses the effects of hot-rolling, press-forging and hammer-forging on strength and ductility, and the influence of cold-rolling, cold-drawing, cold-extrusion and cold-headed operations. The limitations of cold-working owing to work-hardening and the improvements in fatigue limits by surface cold-work are dealt with. Plastic cycles and the anisotropy of hot- and cold-worked steels are considered. It is concluded that the as-cast ingot structure is broken down by hot-working to yield a dense product. The change is accompanied by an increase in tensile and yield properties. The magnitude of this increase is governed by the composition and by the degree of reduction. Cold-working can further increase strength as a result of work-hardening. The products of all the processes given above are anisotropic. Surface cold-working can be used to raise the fatigue limit by introducing compressive stresses in the surface layers. (28 references).—L. E. W.

Influence of Thermal Treatment on the Mechanical Properties of Steels. G. K. Bapat. (*Tisco*, 1956, **3,** July, 135–143). The necessity of heat-treatment for obtaining desired balance of mechanical properties is briefly discussed. This is illustrated by a detailed consideration of the property changes of a 0·40% carbon steel caused by various heat-treatments, such as annealing, normalizing, quenching etc. The author then correlates at some length mechanical properties with microstructure and shows how desired structures may be obtained by suitable heat-treatment. The surface-hardening steel is also dealt with briefly. (16 references).—L. E. W.

Components of the Thermodynamic Functions of Iron. R. J. Weiss and K. J. Tauer. (*Phys. Rev.*, 1956, **102,** June 15, 1490–1495). The existing data are used to determine the enthalpy, entropy and free energy of alpha and gamma iron. The functions are then resolved into their magnetic lattice and electronic components on the basis of additivity of the respective specific heat components. The properties are compared and discussed.—E. E. W.

Plasma Oscillations and the Electron Theory of Metals. S. Raines. (*Research*, 1956, **9,** Oct., 374–380). Calculations of the energy involved in electronic interactions in metals are made in terms of the electron gas concept. Evidence for the existence of these oscillations in metals is presented.

Report of Committee A-1 on Steel. (*Amer. Soc. Test. Mat. Preprint No.* 1, 1956). A number of draft specifications recommended for discussion by the A.S.T.M. committee are given. These are concerned with: steel tubing and plate. Cr–Si valve spring wire, high tensile C–Mn steel plates for unfired pressure vessels, selection of steel bar composition according to section, factory-made wrought austenitic steel welding fittings, forged or rolled alloy-steel pipe parts for high temperature service, and seamless ferritic alloy-steel pipe for high temperature service.—B. G. B.

A Study of (112) Edge Dislocations in Bent Silicon Iron Single Crystals. W. R. Hibbard, Jun. and C. G. Dunn. (*Acta Met.*, 1956, **4,** May, 306–315). [In English]. Information on dislocation densities produced by bending and kinetics of polygon growth are summarized. Data are presented on the density of dislocations as a function of the radius of bending in 3¼ Si-iron crystals by measuring the density of etch pits developed by electrolytic etching in a chromic/acetic acid solution. Isothermal polygon growth was also studied.

Dislocation Relaxation Mechanism. Comments. J. Weertman and W. P. Mason. (*Phys. Rev.*, 1956, **101,** Feb. 15, 1429–1430). Weertman comments that Mason's proposed dislocation relaxation model, which attempts to explain Bordoni's low temperature internal friction peak, gives rise to internal peaks at much lower temperatures than those obtained by Bordoni. A reply by Mason attempts to show that Weertman's criticism is not valid.—E. E. W.

The Effect of Brittle Skins on the Ductility of Metals. G. W. Form and W. M. Baldwin, Jun. (*Amer. Soc. Test. Mat. Preprint No.* 79, 1956). Brittle skins (for example, carburized cases) embrittle an otherwise ductile metal to a greater degree than would be anticipated by the percentage of bulk that the skin occupies. Evidence is given to show that in tension tests on metals with brittle skins, the skin cracks at a negligible strain, and that from this point on, the test is merely a notch tension test of the core. This points out, among other things, that notch-sensitive steels are ill-suited for carburizing purposes.—B. G. B.

Strength, Damping, and Elasticity of Materials under Increasing Reversed Stress with Reference to Accelerated Fatigue Testing. F. H. Vitovec and B. J. Lazan. (*Amer. Soc. Test. Mat. Proceedings* 1955, **55,** 844–865). SAE 4340 steel and Al and Ti alloys were used. Gough, Lehr and Prot methods were compared.

The Use of Paraffin Wax as a Model Material to Simulate the Plastic Behaviour of Metals. Part I—A Preliminary Investigation into the Mechanical Properties of Paraffin Wax. C. Bodsworth, J. Halling, and J. W. Barton. (*J. Iron Steel Inst.*, 1957, **185,** Mar., 375–383). [This issue].

Elastic and Plastic Behaviour of the Ferrite Lattice in a Low Alloy Steel. H. C. Vacher, R. Liss and R. W. Mebs. (*Acta Met.*, 1956, **4,** Sept., 532–540). X-Ray back reflection measurements of lattice strain were made with normalized NE-9420 steel under alternating tension and compression. Analysis of the stress : strain ratio (C) indicated that a transverse compressive stress and a shear stress were superimposed on the axial stress. The lattice elastic limit was higher for negative values of C than for positive values. Analysis of residual strains after deformation showed a compressive stress in the loading direction. It was found possible to calculate loading stresses above the elastic limit.—A. D. H.

The Influence of Strain Rate and Temperature on the Ductility of Austenitic Stainless Steel. G. W. Form and W. M. Baldwin, Jr. (*Trans. Amer. Soc. Metals*, 1956, **48,** 474–485). Tensile tests were made on AISI 303 and 310 austenitic stain-

less steels over a range of strain rates from 0·01 in./in./min up to 19,000 in./in./min and between − 321° up to + 750° F. At low strain rates the maximum ductility occurs at room temperature as test temperature is varied, but at high strain rates the ductility increases as the test temperature is increased. The loss in ductility at high strain rates is greatest at room temperature. Magnetic measurements on broken specimens proved that γ–α transformation cannot account for all these behaviours.—E. E. W.

The Influence of Tensile Stress on the Isothermal Decomposition of Austenite to Ferrite and Pearlite. G. L. Kehl and S. Bhattacharyya. (*Trans. Amer. Soc. Metals*, 1956, **48**, 234–248). It was found that applied stress markedly affected the beginning and ending times of transformation and accelerated the rate of transformation in AISI 1085 steel at 1273° F and in AISI 10B45 steel at 1253° F. Critical observations of fully transformed structures indicated that in general there was no significant alteration arising from stress.—E. E. W.

Strain Gage Transducers. P. K. Stein. (*Product Eng.*, 1956, **27**, March, 196–198). In this article the question of compensating for temperature effects on the gauge materials is discussed. A method of calculating the required compensating series resistor for a bridge is described, and a specimen calculation is included.—E. A. C.

Photoelastic Varnishes in Extensometry. C. M. Boulet. (*Usine Nouvelle*, 1956, **12**, Mar. 15, 87–89; Mar. 22, 90–91). The inconveniences of classical photo-elasticimetry are described. In the method outlined here, the surface of the metal is coated with a skin of plastic, which is strongly active photoelastically, and which follows exactly any deformations. Measurement of local birefringence shows accurately the state of deformation of the metal. One method of applying the plastic film is as a varnish.—T. E. D.

Evaluation of Grey Spots in Fractures of Steel Test-Pieces. R. S. Nikolaev. (*Zavodskaya Laboratoriya*, 1955, **21**, (10), 1201–1203). [In Russian]. Some examples of dark-grey, fibrous spots, observed in fractured steel test-pieces are illustrated and their significance is discussed. It is concluded that the spots do not themselves lead to fracture but are often associated with defects.—S. K.

Bending Creep and its Application to Beam-columns. L. W. Hu and N. H. Triner. (*J. Appl. Mech.*, 1956, **23**, March, 35–42). An analytical procedure has been developed to evaluate the creep deflection of a member subjected to pure bending of constant or varying magnitude based on an assumed creep stress–strain time relationship for simple tension. The application of the theory to beam columns subjected to axial load with large eccentricity has been shown.

Some Relationships between Endurance Limit and Torsional Properties of Steel. S. T. Ross, R. P. Sernka, and W. E. Jominy. (*Trans. Amer. Soc. Metals*, 1956, **48**, 119–148). Torsional yield strength-hardness data may be used to determine the maximum endurance limit of tempered low alloy steels. The relation is linear up to a region of high hardness where instability occurs. The microstructure has been examined in this region. Three types of failure under torsion have been obtained.—E. E. W.

The Nature of Ageing of Binary Iron–Chromium Alloys around 500° C. R. O. Williams and H. W. Paxton. (*J. Iron Steel Inst.*, 1957, **185**, Mar., 358–374). [This issue].

Cross-Shaped Reverser for Testing Materials for Two-Sided Compression. I. N. Vinogradov and Yu. I. Yagn. (*Zavodskaya Laboratoriya*, 1955, **21**, (8), 986–988). [In Russian]. The reverser described enables two-sided compression tests to be applied in a normal press, with the possibility of varying the ratio of the two compression forces from 1 to 2·4, by adjusting the lengths of the diagonals. The adjustment being continued during the test to allow for deformation of the test-piece. The device has been used for investigations with large deformations and for plastic deformation curves for metals both under two-axial and under three-axial compression; the additional device for the latter is also described.—S. K.

Experiments on the Use of Carbon Strain Gauges in Measuring Compression Forces. V. N. Garbaruk. (*Zavodskaya Laboratoriya*, 1955, **21**, (8), 989–990). [In Russian]. A brief account is given of the use of carbon resistance strain gauges under the following conditions: eccentric application of load; with preliminary gauge compression; loading of gauge without preliminary compression.—S. K.

Some Recent Investigations into the Design of Pressure Components. P. H. R. Lane. (*Chem. Process Eng.*, 1956, **37**, April, 111–115). The author describes some investigations which have been carried out to increase knowledge of stress systems in pressure vessels and piping components, and to provide a basis on which design methods may be made both more economical and more rational. (21 references).—L. E. W.

Experience in Impact Testing with Full-Scale Test-Pieces. G. V. Zarochentsev. (*Zavodskaya Laboratoriya*, 1955, **21**, (8), 965–971). [In Russian]. Complications in impact tests due to size changes are avoided if full-scale test-pieces are used and the present article describes methods for such tests. The determination of the brittleness and cold-shortness of rails is used as an example and results obtained are presented. Tests were carried out at + 20, to − 80° C, the rails being cooled with the aid of liquid oxygen in a special chamber. High-speed (1000 frames per s) cine-recording enabled the mechanism of the fracture to be followed. From an analysis of the results conclusions on the desirability of full-scale tests and their methodology are drawn.—S. K.

V-Notch Charpy Impact Testing of Weld Metal and Heat Affected Zone Simultaneously. W. P. Hatch and C. F. Hartbower. (*Welding J.*, 1956, **35**, March, 120s–126s). A method is described with which to evaluate simultaneously the notch toughness of weld metal and heat-affected zone in a multiple bead-on-plate weld using the standard **V**-notch Charpy impact specimen. It was found that the composite test was sensitive to variations in weld metal and heat-affected zone toughness, and to a seemingly minor variation in welding procedure.—U. E.

Investigation of the Influence of Deoxidation and Chemical Composition on Notched-Bar Properties of Ship Plate Steels. F. W. Boulger, R. H. Frazier, and C. H. Lorig. (*Welding Res. Council Bull. Ser.*, 1956, No. 26, April). Results are presented of an investigation of some 400 heats of steel on the effects of variations in composition and deoxidation practice on the fracture characteristics of ship plate steel.

Evaluation of the Significance of Charpy Tests for Quenched and Tempered Steels. P. P. Puzak, W. S. Pellini. (*Welding J.*, 1956, **35**, June, 275s–290s). Crack-starter tests of various high strength steels have been carried out to determine the critical fracture transition temperatures at which welded structures, loaded in the presence of sharp, crack-like defects, may initiate or propagate brittle fracture. Correlation studies of Charpy **V** and keyhole transition curves are presented.

Notch Toughness of Hull Quality Ship Steel Evaluated by Means of Keyhole and V-Notch Charpy Tests. A. Audigé. (*Soudage Techn. Connexes*, 1956, **10**, Jan.-Feb., 13–22). The programme of research is outlined, and the results of the two types of test are correlated. They are also compared with results obtained by foreign workers. The value of the various criteria proposed for the classification of weldable steels is examined. (*See also Schweissen u. Schneiden*, 1956, **8**, July, 256–261).

Some Notes on Notch Brittleness and Brittle Fractures in Mild Steel. L. C. Bogan. (*Proc. Australasian Inst. Min. Met.*, 1954, Sept.-Dec., 45–73). A review of this subject is presented. The theoretical principles underlying brittle fracture are discussed and methods used for testing for notch brittleness are considered. A number of examples of the failure of mild steel parts by brittle fracture are described.—B. G. B.

Influence of Alloying Elements on the Impact Transition Behaviour of 12% Chromium Steels Aged at 900° F. E. J. Whittenberger and E. R. Rosenow. (*Trans. Amer. Soc. Metals*, 1956, **48**, 391–417). The effect is described of variations in the C, Cr, Mo, Al, and Ti contents on the Charpy **V** test transition temperature of 12% Cr steels aged at 900° F for 10,000 hours. Contrary to previous results, the addition of 0·25% Al was found to have no effect.—E. E. W.

Measurement of Deformations with the Aid of a Draw-On Ring in the Study of Residual Stresses by Sach's Method. M. M. Kobrin. (*Zavodskaya Laboratoriya*, 1955, **21**, (10), 1229–1235). [In Russian]. The method proposed for studying residual stresses in shafts consists essentially in the use of a tightly drawn on ring to indicate the deformation of a shaft being bored out, i.e. while its residual stresses are being removed. The method is based on the different character of the change of the strength of the pressed joint when residual stresses are present. The method is particularly suitable for discs. The theory of the method is discussed, some results are given and possible simplifications indicated.—S. K.

Static Fatigue in High Strength Steel. R. H. Raring and J. A. Rinebolt. (*Trans. Amer. Soc. Metals*, 1956, **48**, 198–212).

The effects of melting in a vacuum or in argon on the susceptibility to static fatigue of AISI 4340 steel, heat-treated to high strength levels, and of baking treatments to effect recovery of plated steels are described.—E. E. W.

Breakage Processes in Metals. C. Schaub. (*Radex-Rundschau*, 1956, March, 60–65). A classification of processes of fracture is presented and fatigue processes are linked up with glide plane mechanisms.

Fatigue of Metals under Random Loads. A. K. Head and F. H. Hooke. (*Nature*, 1956, **177**, June 23, 1176–1177). Results obtained during the fatigue testing of an aluminium alloy subjected to a random stress wave form are discussed. The fatigue life as predicted by Miner's rule is longer than that found experimentally by a factor of 2 to 3·5.—B. G. B.

Methods of Evaluating the Tendency of Different Types of Structural Steels to Mechanical Ageing. E. S. Volokhvyanskaya and N. P. Shchapov. (*Zavodskaya Laboratoriya*, 1955, **21**, (10), 1215–1223). [In Russian]. This is a critical review, based partly on the author's own work, of methods for evaluating the tendency of structural steels to undergo mechanical ageing.—S. K.

New Machine for Fatigue-Tests on Thin Sheet Metal. I. M. Roitman. (*Zavodskaya Laboratoriya*, 1955, **21**, (8), 983–985). [In Russian]. A new fatigue-testing machine, developed at the Soviet Weights and Apparatus Research Institute, is described in which the thin test-piece is subjected to pure bending. Test pieces 0·2–1 mm thick can be subjected to maximal bending moments of ± 15 kg/cm with a symmetrical loading cycle of 22 kg/cm when the cycle is non-symmetrical, the maximal deflection and cyclic loading frequency being ± 30° C and 50 cycles/s. The theory of producing pure bending at high frequencies is considered and data are given on the accuracy of test results.—S. K.

New Machine for Programmed Fatigue-Tests. M. E. Garf. (*Zavodskaya Laboratoriya*, 1955, **21**, (10), 1238–1241). [In Russian]. The testing machine described enables fatigue tests at two or more stress-levels to be carried out with a wide variety of programmes. The load is applied by an electrically-controlled spring.—S. K.

Systematic Care and Maintenance of Wire Ropes. W. M. Halliday. (*Wire Ind.*, 1955, **22**, Dec., 1177–1179). Factors influencing the service life of conveying and transmission ropes are discussed. Visual inspection and its limitations, effects of fatigue, oscillations, and internal friction are considered and their effects on strength and on external appearance described.

An Unusual Fatigue Failure. E. Wood. (*Metallurgia*, 1956, **53**, June, 278–279). The failure of an engineer's hammer in service is considered. The cause of the fatigue stress is discussed but the possible explanations are not considered entirely satisfactory.—B. G. B.

Effect of Cold Work on the Mechanical Properties of Pressure Vessel Steels. W. T. Lankford. (*Welding J.*, 1956, **35**, April, 195s–206s). The present state of knowledge regarding the effects of cold work on the mechanical properties of steels is reviewed. (37 references).—U. E.

Investigations into Blade-Root Fixings of High Temperature Steels. W. Siegfried. (*Trans. Amer. Soc. Mech. Eng.*, 1956, **78**, Feb., 327–338). Room temperature tensile and elevated temperature fixings employing the fir-tree root technique. The notch sensitivity of various austenitic and ferritic creep-resisting steels used in these fixings was determined by creep tests (stress for 1% total strain in 1000 hours) on smooth and notched specimens. Results indicate that the design stress figures obtained from creep tests may be reduced by 50% if the steel is lacking in the ductility required by the structural design employed.—D. H.

The Fatigue Strength of Specimens Containing Cracks. N. E. Frost and C. E. Phillips. (*Inst. Mechanical Eng.*, 1956, Preprint, 19–31). Strength-reduction factors are measured under conditions of rotating-bending and reversed-direct stress for mild steel, a Ni–Cr steel, and an Al alloy.

Fatigue under Triaxial Stress: Development of a Testing Machine and Preliminary Results. J. L. M. Morrison, B. Crossland, and J. S. C. Parry. (*Inst. Mechanical Eng.*, 1956, Preprint, pp. 3–18). The apparatus is described and the case of a thick cylinder is considered.

Factors Influencing the Notch Fatigue Strengthening of N-155 Alloy at Elevated Temperatures. W. S. Hyler. (*Trans. Amer. Soc. Mech. Eng.*, 1956, **78**, Feb., 339–348). Data are given to illustrate the effect of stress raisers on the elevated-temperature fatigue behaviour of N-155 alloy (0·13% C, 1·64% Mn, 27·22% Cr, 19·0% Ni, 19·7% Co, 2·9% Mo, 2·61% W, 0·84% Nb). The data were obtained on specimens with V-grooves having various root radii and notch severities. Tests were in direct-stress fatigue with alternating stress/mean stress ratio A = 0·0 to A = ∞ at temperatures of 1200–1500° F. The effect of surface finish was studied together with the metallography of the fractures.—D. H.

The Effect of Composition and Structure on the Creep-Rupture Properties of 18–8 Stainless Steels. F. C. Monkman, P. E. Price, and N. J. Grant. (*Trans. Amer. Soc. Metals*, 1956, **48**, 418–445). Stress-rupture tests at 1000, 1200, and 1300° F were conducted on 27 simple unstabilized 18/8 stainless steels containing varying amounts of Cr, Ni, and carbon plus nitrogen. An evaluation is given of the effects of the formation and growth of carbides, ferrite, and sigma during the tests.—E. E. W.

Creep-Rupture Properties of Cold-Worked Type 347 Stainless Steel. N. J. Grant, A. G. Bucklin, and W. Rowland. (*Trans. Amer. Soc. Metals*, 1956, **48**, 446–455). Recrystallization temperatures for 0·5, 5, and 50 hour intervals were determined on a 60% cold worked Nb stabilized stainless steel. Tensile tests at room temperature and creep rupture tests at 1200, 1300, and 1500° F were also made to study the effects of cold work and to relate time–temperature values for the incidence of intercrystalline fracture to the static recrystallization temperature.—E. E. W.

Migration of Grain Boundaries during Creep. Mechanism of Migration. D. McLean. (*Rev. Mét.*, 1956, **53**, Feb., 139–146). This paper, in two parts, tests, but does not support the suggestion that sliding at grain boundaries depends upon the smoothing out of irregularities by migration. They are shown to have different temperature coefficients, and a study of atomic processes suggests diffusion along the boundary as a mechanism of migration.

Progress Reports of Investigation of Railroad Rails and Joint Bars. R. E. Cramer and R. S. Jensen. (*Illinois Univ. Eng. Exper. Sta. Bull. Reprint Series* 55, 1956, May, pp. 30). Reports on 43 failures in service with micrographs, and observations on shelly failures are presented.

Development and Application of the Iso-Hardness Diagram. A. E. Gurley and C. R. Hannewald. (*Metal Treating*, 1956, **7**, May-June, 2–6, 32). A method of representing hardness data for carburized end-quench bar tests is described. Parallel flats are ground on the bar and, after treatment, hardnesses are determined and the flats reground and the hardness again measured and the process repeated until the hardness measured is that of the original metal. The carbon gradient is determined by analysis and hardness is plotted against carbon content in a simplified form.

On Hardness Determination on Plain and Low-alloy Steel. E. Greulich. (*Draht, German Ed.*, 1956, **7**, Mar., 75–77). Measurements are made showing the effect of alloying elements and of austenite treatment and surface quenching.

Change of Hardness in Steel due to Hydrogen. H. G. Vaughan and M. E. de Morton. (*Nature*, 1956, **177**, June 30, 1225). A change in the hardness value of a steel due to the presence of diffusible hydrogen has been detected and found to be in agreement with that predicted from the change in the work hardening characteristics of the particular steel.

On the Problem of Brittleness in Transformer Steels. V. Rauner and M. Zezulová. (*Hutnické Listy*, 1956, **11**, (3), 134–139). [In Czech]. Micrography, hardness tests, and chemical analysis were used to study the bend-brittleness of the sheet. Brittleness was found to be associated with the precipitation of a hard intergranular constituent, which is generally associated with a coarsening of the alpha-phase grains. Highly brittle grains were found to have a higher carbon and silicon content than the average obtained by macro-analysis. Methods of rolling and heat-treatments leading to brittleness, as well as those by which brittleness is prevented were studied.—P. F.

State of Brittle Fracture Problems with Reference to the Classification of Steels. K. Rühl. (*Schweissen u. Schneiden*, 1956, **8**, April, 107–115). A number of examples are given of tests for determining the tendency to brittle fracture, i.e. Charpy-**V** test, Van-der-Veen bend test, and the Schnadt test. An attempt has been made to standardize brittle fracture tests for structural steels.—U. E.

Method of Evaluating the Embrittlement of Steel in Blue Brittleness. G. I. Pogodin-Alekseev. (*Zavodskaya Labora-*

toriya, 1955, **21**, (8), 971–974). [In Russian]. The effects of cold-shortness and blue-brittleness are compared and criteria for the evaluation of the latter are discussed on the basis of static and impact tests. The criteria proposed are numerical values of the upper and lower limits of the blue-brittleness temperature range and their relative changes through the influence of embrittling factors; the extent of the temperature range; the relative reduction of toughness or plasticity at maximum blue-brittleness. Their use avoids the occurrence of the misleading results often obtained when only the temperature of maximum blue-brittleness is determined.—S. K.

Hot Crack Testing of Weld Metal Deposits. J. W. Shedden. (*Australasian Eng.*, 1956, **48**, Mar., 68–73). A hot-crack bend test is developed and a simplified test machine constructed. Tests with welding rods are described, and the effects of inclusions, of carbon and nickel content, and of hydrogen in weld metal are investigated.

An Approach to Wear Evaluation. A. Siede and V. Pulsifer. (*Machine Design*, 1956, **28**, Jan. 12, 101–102). A new method of determining characteristic wear rates of materials for practical design use has been incorporated in a machine designed and constructed at Armour Research Foundation of Illinois Institute of Technology.—M. A. K.

Contribution to the Problem of the Measurement of Surface Roughness. H. Bühler and W. Schreiber. (*Draht, German Ed.*, 1956, **7**, Mar., 85–87). Measurements made with apparatus from Elektro-Spezial, Hamburg, are recorded on 22 steel samples. Readings were taken ten times on each of ten steels by two different operators and the coefficients of variation are calculated. Measurements on wire are also given.

Investigations of the Effect of the Wear of Wire Ropes on their Servicability. E. A. Franke. (*Draht, German Ed.*, 1956, **7**, Apr., 124–129). Wire ropes were tested for wear resistance by running them over various arrangements of pulleys under different loads. Tensile, bending, torsion, and vibration tests were carried out on the abraded samples. The results are only to be interpreted in a general way.

Measuring Gear Tooth Wear. G. Uberti. (*J. Amer. Soc. Naval Eng.*, 1956, **68**, Feb., 151–153).

Device for Mounting Test-Pieces on a Type MI Friction Testing Machine. Sh. Z. Zakirov and V. B. Lyadskiĭ. (*Zavodskaya Laboratoriya*, 1955, **21**, (10), 1245–1246). [In Russian]. A device which has greatly improved the reproducibility of dry-friction tests of ferrous materials is described. It enables the test-pieces to be fixed reliably in the testing machine.

Considerations on Different Types of Wear of Ferrous Alloys and on the Various Types of Hard Facing. (*Usine Nouvelle*, 1956, **12**, Mar. 22, 33–38; *Philips' Technical Information* Nos. 1 and 2). Wear through shock, abrasion, and friction are examined. The metallurgical aspects of hard facing are considered, with particular reference to facing by manual arc welding. Hard facing of white cast iron, cast steel, and austenitic manganese steel are outlined. Facing of new items is mentioned.—T. E. D.

Thermomagnetic Apparatus of High Sensitivity for Studies of Phase Transformations in Steels. A. N. Alfimov. (*Zhur. Tekhn. Fiz.*, **25**, (6), 1105–1110). [In Russian]. A description of the apparatus is given. Maximum sensitivity (the amount of ferromagnetic phase, causing shift of 1 mm on the scale) is claimed to be $4 \cdot 1 \times 10^{-8}$ g or in per cent of the volume of the specimen (diam. = 5 mm, l = 30 mm), $2 \cdot 5 \times 10^{-6}$.

Investigation of the Tempering of Steel by Measuring Magnetic Saturation. E. N. Kislyakova and E. M. Shiraeva. (*Zavodskaya Laboratoriya*, 155, **21**, (8), 960–962). [In Russian]. In the method described, carbide content changes in steel were followed by determination of magnetic saturation at 250–300° C. This elevated temperature resulted in greater sensitivity. Impact specimens of type U8 steel and low- and medium-carbon alloy steels were used and curves showing the variation with temperature in the range 250–700° C of the difference between magnetic-saturation values measured at room temperature and at 250° C, are given, this difference being almost proportional to the quantity of carbide formed. Results obtained are discussed in terms of the carbon and alloying element contents of the steels.—S. K.

Local Magnetic Powder Defectoscopy. N. V. Miroshin. (*Zavodskaya Laboratoriya*, 1955, **21**, (10), 1197–1198). [In Russian]. Cracks in complicated ferro-magnetic parts are conveniently detected with the aid of a pointed bar-magnet previously dipped in magnetic powder. The magnet is moved over the surface in two mutually perpendicular directions.—S. K.

Application of the Bitter (Iron Filings) Technique for Revealing Domain Structure. H. Fahlenbrach. (*Metall*, 1956, **10**, May, 393–399).

Luminescence Method for Finding Thin Cracks in Refractory Products and Brick Clay. D. M. Shakhtin. (*Zavodskaya Laboratoriya*, 1955, **21**, (10), 1200–1201). [In Russian]. In the method of crack detection briefly described, a luminophor is brushed on to the surface of the fired or unfired refractory. The cracks appear as dark lines on irradiation after a few seconds.—S. K.

Effect of Manganese Content on the Thermal Expansion and Magnetic Properties of "Dumet" Iron-Nickel Alloys. T. Millner and R. Welesz. (*Acta Techn.*, 1956, **14**, (3–4), 279–291). [In English]. Experiments on these 44% Ni alloys showed that replacement of some of the iron by manganese, up to 3% Mn, leads to a progressive lowering of the range of anomalous expansion, from 460–370° C to 400–300° C, the lowering being even more pronounced with higher manganese contents. As the anomalous expansion is utilized in processes requiring glass-to-metal seals, it must be kept at the highest temperatures, and manganese should not thus be present in amounts greater than 1%.—P. F.

Ferromagnetism in Relation to Engineering Magnetic Materials. A Review of Progress. F. Brailsford. (*Proc. Inst. Elect. Eng.*, 1956, **103**, Part A, Feb., 40–51). This is a review of theoretical and experimental work on ferromagnetism carried out mainly within the past ten years. Commencing with an account of the earlier development of quantitative theories of magnetization, the paper reviews the geometry of domain, including a discussion of difficulties met with in attempts to establish a general theory of magnetization, and a treatment of modern theories accounting for the high coercivity possessed by permanent magnet materials. A description of the ferrites and ferrimagnetism is given.—L. D. H.

The Demagnetization Curve of Materials for Magnets. F. Nuñez. (*Rev. Cienca Apl.*, 1956, **10**, Jan.-Feb., 30–33). [In Spanish]. An experimental determination of the demagnetization curves for an Alnico alloy and a cobalt steel is described. The experimental circuit, which uses a ballistic galvanometer is given; the test-pieces being placed between the pole-pieces of an electro-magnet. H was measured either by a magnetic potentiometer (2 cm length, 117 cm² effective section) or by one of two plane coils of rectangular section (6 mm; effective section 10·9 cm, and 24 mm; effective section 28 cm²). Curves showing (*a*) the distribution of the magnetic field along of 3 cm Alnico bar magnet, (*b*) variation in H as a function of the distance of the coil from the surface, and (*c*) demagnetization of Koerzit, Alnico, and a cobalt steel are given.

Domain Walls in Antiferromagnets and the Weak Ferromagnetism of αFe_2O_3. Yin-Yuan Li. (*Phys. Rev.*, 1956, **101**, Mar. 1, 1450–1454). A description is given of the relation between energy and entropy and also the magnetization of domain walls. An explanation is advanced for the weak ferromagnetism of hematite and an interpretation of the experimental results is made.—E. E. W.

SIMAC—Sonic Inspection, Measurement, and Control. F. E. Pringle, Jun. (*Nondestructive Test.*, 1956, **14**, May-June, 22–25, 28). A detailed account is given of ultrasonic equipment, and methods of presenting the findings. The possibility of automation is discussed.

Ultrasonic Testing of Materials. W. Breitling. (*Draht, German Ed.*, 1956, **7**, Mar., 77–81).

Application of the Ultrasonic Method in Metallurgy, Mechanical Engineering, Maintenance, Before, During and After Service. J. L. Pignet. (*Centre Doc. Sidér., Circ. Inform. Techn.*, 1956, **13**, No. 6, 1213–1237). A number of examples of non-destructive testing are described in which an ultrasonic method is used either alone or in conjunction with radiography or other methods.—T. E. D.

Provisional Instruction No. 102 of Indret, issued 15th October 1954, concerning the Ultrasonic Examination of Thick Sheet. (*Centre Doc. Sidér., Circ. Inform. Techn.*, 1956, **13**, No. 2, 373–384). The method for examination of sheet at least 30 mm thick is described. The reflection method is used. Comments on the method by MM. Borione and Beaujard (IRSID) are reported.—T. E. D.

Ultra-Sonic Detection of Laminations in Metal Without Polishing the Surface. L. B. Pirozhnikov and I. S. Vainshtok. (*Zavodskaya Laboratoriya*, 1955, **21**, (10), 1198–1200). [In

Russian]. In the procedure described, laminations are detected by the shadow method at a frequency of 900 kilo-Hertz and with electronic frequency modulation.—S. K.

Zeiss Ultrasonic Visual Testing Equipment. (*Machinery*, 1956, **88**, Feb. 17, 279–280, 266). The apparatus with Schlieren optical projection system is described and illustrated and typical visual images are shown.

Tests That Save. A. L. Pace. (*Steel*, 1956, **138**, May 21, 124–127). The capabilities of non-destructive tests using ultrasonics, magnetism, X-rays, black light, and radiographics are indicated.—D. L. C. P.

Nondestructive Testing in Construction of the Aircraft Carrier "Saratoga." J. L. Cahill. (*Non-Destructive Test.*, 1956, **14**, Jan.-Feb., 16–18). The article describes the application of field radiography, magnetic-particle inspection and other methods.—A. H. M.

Nondestructive Testing on the Southern Pacific Railroad. A. S. Pedrick. (*Nondestructive Test.*, 1956, **14**, May-June, 10–13, 16). A general account is given, with illustrations of the kinds of flaw detected.

Non-destructive Testing of Steel Castings. J. R. Rait. (*B.S.F.A. Bulletin*, 1956, **2**, May, 3–11).

Modern Fluoroscopic Practices. W. R. Hampe. (*Non-Destructive Test.*, 1956, **14**, Jan.-Feb., 36–40). The fundamental requirements for optimum fluoroscopy and their applications to the basic geometric arrangements of the screen, tube parts to be examined, and X-ray protection are discussed. Cine-fluorography and television projection are described.—A. H. M.

The Surface Tension of Liquid-Metal Solutions. J. W. Taylor. (*Acta Met.*, 1956, **4**, Sept., 460–468). Two methods are presented for the calculation of the surface tensions of binary liquid alloys and the results are compared with experimental values for 10 alloy systems. For eutectic systems, the agreement was good but considerable discrepancies arose when intermediate phases were formed.—A. D. H.

Determination of Surface Tension in Pure and Alloyed Iron. W. v. d. Esche and O. Peter. (*Arch. Eisenhüttenwesen*, 1956, **27**, June, 355–366). Experiments to measure the surface tension of molten iron were carried out using a special heating microscope to examine quiescent drops. Alloyed iron was investigated in the temperature zone 1300–1700° C. Sulphur and oxygen were found sharply to reduce surface tension. Specimens (nearly free from sulphur and oxygen) containing silicon and carbon showed surface tensions up to 1900 dyne/cm. The effects of temperature were attributed to varying states of de-oxidation in the specimens. Transient changes are discussed by the authors.

Gases in Iron and Steel. N. A. Parlee. (*Foundry*, 1956, **84**, Aug., 80–87). The problem of gases in metals is discussed with particular reference to the laws governing the solubility of diatomic and triatomic gases in liquid metals. The factors affecting the solubility of oxygen, nitrogen and hydrogen in liquid steel are reviewed and the limited data available on the behaviour of gases in cast irons are briefly considered. (37 references).—B. C. W.

Role of the Porosity of Cast Steel in the Segregation of Hydrogen. J. Drain and P. Bastien. (*Compt. Rend.*, 1955, **241**, Nov. 28, 1573–1575). The hydrogen content of steel ingot sections is related to the porosity, defined in terms of its apparent density. It is shown that there is a progressive increase in the hydrogen content from the outside surface to the centre. It has also been verified that the hydrogen content is inversely proportional to the apparent density for a given ingot section.—G. E. D.

Effect of Chemical Composition on the Properties of Steel. B. R. Nijhawan. (*Tisco*, 1956, **3**, July, 104–112). The author reviews the effects caused by the introduction of different elements into various microconstituents and the effects caused by composition on the response to thermal treatment. No attempt is made to deal with tramp impurities and gaseous elements. Particular reference is made to the influence of carbon, manganese, sulphur, silicon and phosphorus and to the effects of alloying elements such as Ni, Cr, Mo etc.—L. E. W.

Theory and Practice of High Speed Steels Containing Aluminium. R. Mitsche. (*Inst. Hierro Acero*, 1956, **9**, Apr., 375–385. Special Number). [In Spanish]. A discussion is given of the development of more economically alloyed high speed steels, with particular reference to the use of aluminium. After reviewing previous work, the author gives the results of a series of tests on (*a*) a series of 4 Cr, 3 W, 3 Mo, 3 V type steels with 1, 1·5 or 2% carbon and 0·85 or 1·1% aluminium and (*b*) a series of 1 C, 4 Cr, 2·5 Mo, 2·5 V type steels with 1·5 or 3% tungsten 1·1 or 0·85% aluminium, and 0, 0·05 or 0·08% nitrogen. The first series indicated that the 1% carbon steel had a better low speed cutting performance than a standard 10% tungsten type. No definite advantages from adding nitrogen were found, but the results of this latter series showed that a 1% aluminium addition brought the 1·5% tungsten steel up to the same standard as the 3% tungsten aluminium-free type of steel.—P. S.

A Note on the Subject of the Mechanical Properties of Grey Cast Irons. Verification of the Diagram Established by A. Collaud. M. Ferry. (*Fonderie*, 1956, May, 177–184). Data obtained on 30 mm diameter test bars of grey cast irons are analysed in terms of the correlation between tensile strength and elastic modulus and Brinell hardness. Some similar results obtained on test bars of different diameters are briefly presented. The results were found to be in good agreement with those obtained by Collaud except for the elastic modulus figures for the different ranges of tensile strength. If suitable corrections are applied to the results obtained for the irons with $P > 0{\cdot}35\%$ all the data can be represented by one scatter band when Brinell hardness or elastic modulus is plotted against tensile strength.—B. C. W.

Variations in the Structure across the Thickness of the Scale in Nickel Steels. K. Sachs. (*J. Iron Steel Inst.*, 1957, **185**, Mar., 348–357). [This issue].

Quenching Deformation of a 12% Chromium, 2% Carbon Steel. F. Joanxich Ayma. (*Inst. Hierro Acero*, 1956, **9**, Apr., 364–374. Special Number). [In Spanish]. The effect of quenching and tempering upon the dimensional stability and hardness of three high-carbon, high-chromium steels has been studied in relationship with the carbide distribution. No definite correlation with the latter could be observed though the distortion is more anistropic when the carbides are markedly heterogeneously distributed. The distortion is more severe but less anistropic after a high temperature quench (1010° C) and this temperature was the only one which gave satisfactory tool steel hardnesses. These higher dimensional changes were offset by tempering at 500° C, which still retained a reasonably hard structure.—P. S.

An Investigation of the 21%Cr - 10%Ni Heat-resisting Casting Alloy. R. J. Mangone, D. D. Burgan and A. M. Hall. (*Amer. Soc. Test. Mat. Proceedings*, 1955, **55**, 765–792). Changes in Ni, Cr, C and N were investigated. The alloy is austenitic but may contain ferrite and sigma. Excess C forms eutectic carbides and secondary carbides may precipitate at 1400–1500° F. Agglomeration and spheroidization occur at 1900° F and above. Tensile behaviour and stress rupture at high temperatures were studied and resistance to thermal fatigue cracking was observed and means to increase it were found.

Cracking of DTD 247: Failure of High Thermal Expansion Alloy. M. H. Davies. (*Iron Steel*, 1956, **29**, June, 321–322). The failure by transcrystalline cracking of the high thermal expansion alloy DTD 247 was found to be restricted to parts machined from bar stock showing moderate to heavy surface deformation. An annealing treatment after machining prevented these failures.—G. F.

Development and Use of Specification for Cast-Iron Pressure Pipe and Fittings. J. W. Mackay. (*J. Amer. Water Works Assoc.*, 1956, **48**, July, 863–888). An introduction is given to the use of specifications for cast iron pipes centrifugally cast. A brief review of the limitations of the older specifications is given together with an explanation of the application of modern specifications.—B. G. B.

Austenitic Manganese Steel: Effect of Heat Treatment on Metallography and Mechanical Properties. K. J. Irvine and F. B. Pickering. (*Iron Steel*, 1956, **29**, Apr., 135–139; May, 169–170). The authors have examined the metallography and mechanical properties of austenitic manganese steel under different conditions of heat treatment. Transformation takes place when the steel is reheated in the range 300–900° C, increasing amounts leading to greatly increased hardness values. The carbide formed at all temperatures is $Fe(Mn)_3C$, containing large amounts of manganese in solid solution. Reheating to 400–700° C greatly reduces both ductility and fracture stress.—G. F.

U.S. Steel Opens New Research Center. (*Steel Processing*, 1956, **42**, June, 341–343, 350). Some representative activities in fundamental and applied research are outlined.—A. H. M.

METALLOGRAPHY

Theory of Alloy Phases. (*American Society for Metals Seminar, Philadelphia*, 1955). **The Band Theory of Bonding in Metals.** J. C. Slater. (1–12). After reference to the Schrödinger equation and tests for approximate solutions, mention is made of work on molecular structure and then of energy bands in crystals, especially in semiconductors. Energy band theory is then developed. **X-Ray Spectroscopy of Solids.** C. H. Shaw. (13–62). A short historical introduction is followed by a section on instrumentation and then by consideration of K-, L-, and M-series spectra. (355 references). **Intermediate Phases and Electronic Structure.** T. B. Massalski. (63–123). Atomic bonding forces are considered and electron theory and electron compounds of 3/2, 21/13, and 7/4 types. Structural defects and electron transfers are then considered, and other features of Brillouin Zone theory. (139 references). **Crystal Structure and Atomic Size.** F. Laves. (124–198). A discussion of intermetallic compounds and atomic replacement in lattices. (96 references). **Electronic Structure of Metals and Alloys.** L. Pauling. (220–242). Valency problems and chemical bonding in intermetallic compounds are reviewed. **Intermediate Phases in Alloys of the Transition Elements.** P. Duwez. (243–254). Sigma structure and other complex phases are considered. (48 references). **Ferromagnetism and Crystal Structure of Iron Alloys.** U. Roesler, H. Sato and C. Zener. (255–263). Allotropic phase boundary theory and the influence of short range magnetic order in binary alloys are discussed. **Atomic and Magnetic Ordering in Transition Metal Structures.** J. S. Kasper. (264–278). Sigma phase and other structures are considered. **Atomic Magnetic Moments of Transition Elements in Solid Solution Alloys.** C. G. Shull. (279–289). Discussion (290–300). **Structure of Solid Solutions.** B. L. Averbach. (301–319). Discussion. (320). **Alloy Phase Diagrams.** G. V. Raynor. (321–270). Mainly non-ferrous systems are discussed. (39 references).

Thermodynamics of Iron–Carbon Melts. E. T. Turkdogan, L. E. Leake and C. R. Masson. (*Acta Met.*, 1956, **4**, July, 396–406). [In English]. Direct measurement of the activity of carbon was made by equilibrating methane over iron–carbon melts over the range from medium carbon to saturation at 1300°–1400° C and 1500° C. The relationship between the activity coefficient and the atom fraction of carbon does not follow a particular solution law. The effect of carbon on the activity coefficient of oxygen dissolved in molten iron containing 0–5% C is calculated.—A. D. H.

Decomposition of Austenite and Martensite. A. E. Austin and C. M. Schwartz. (*Amer. Soc. Test. Mat., Proceedings*, 1955, **55**, 623–625). A new phase was detected in eutectoid carbon steel by electron diffraction.

Hardenability and Transformation Behaviour of Steels. F. Wever and A. Rose. (*Forschungsberichte des Wirtschafts- und Verkekrsministeriums Nordrhein-Westfalen*, 1955, No. 143, pp. 33). Hardenability is defined (as ability to form, on the surface or throughout, a much harder structure consisting of martensite or an intermediate) and measured on round test-pieces, and by end-quench bars, and the latter is used to follow transformations also. Fifteen different alloy steels are tabulated. (10 references).

Kinetics of the $\alpha-\gamma$ Transformation during Rapid Heating of Carbon Steel with Different Degrees of Pearlite Dispersion. V. N. Svechnikov, V. N. Gridnev, and Yu. A. Kocherzhinskii. (*Doklady Akad. Nauk SSSR*, 1955, **103**, (6), 1025–1026). Coarse pearlitic, sorbitic and martensitic samples were studied by dilatometry. The transformation kinetics were derived from thermal measurements.

The Role of the Grain Boundaries and the Allotropic $\alpha-\gamma$ Transformation for Iron in the Elimination of Pores During the Sintering of Carbonyl Iron. G. Cizeron and P. Lacombe. (*Compt. Rend.*, 1955, **241**, July 25, 409–411). The possibility of completely eliminating pores with a single isothermal sintering treatment depends on a continuous and progressive grain growth, provided the iron remains in the α-phase. If the $\alpha-\gamma$ transformation takes place, the grain growth is discontinuous and magnified, the result being that the pores have no chance of being fully eliminated.—G. E. D.

Thermoelectric Study of Transformations in Iron–Chrome Alloys. G. Pomey and J. Philibert. (*Compt. Rend.*, 1955, **241**, Oct. 3, 877–879). By measuring the rate of change in thermoelectric power during the heating of iron–chrome alloys (approximately equiatomic composition), it is shown that it possible to differentiate between the order-disorder and the $\alpha \rightleftharpoons \sigma$ transformations. The results are for an alloy containing 44·80% at. Cr.—G. E. D.

Isothermal Transformations Diagram for a Silicon-Chromium Steel. C. J. Osborn. (*Australasian Eng.*, 1956, **48**, Feb., 63–64). A steel of type SAE 9254 is used for dilatometric measurements and the diagram and its uses described.

Determination of the Transformation Points for Pure Iron. C. Boulanger. (*Compt. Rend.*, 1955, **241**, Oct., 24, 1133–1135). Using "spectroscopically pure" iron and differential thermal analysis, the transformation points have been rechecked and compared with those published in the international thermometric scale of 1927 and Metals Handbook of 1948. The new values proposed are, to the nearest degree, as follows: Curie point, 769° C; AC_3 point, 911° C; AC_4 point, 1392° C; melting point, 1536° C.—G. E. D.

Influence of the Purity and Structure of the Metal on the Solubility of Oxygen in Iron. R. Sifferlen. (*Compt. Rend.*, 1955, **240**, June 27, 2526–2528). Small plates of very high purity iron were oxidized in suitable hydrogen-steam concentrations at 850° C. After removal of the oxide layer formed, the specimens were examined microscopically for the presence of oxide inclusions. After long annealing at 880° C, no inclusions were visible and the oxygen content fell to 0·011% by weight. The extremely low oxygen contents are considered to be related to the annealing time and temperature.—G. E. D.

An Approach to the Study of the Effect of Rare Earth Additions to Steel by Use of Radioactive Tracer Techniques. C. S. DuMont, J. E. Gates and C. M. Henderson. (*Trans. Amer. Soc. Metals*, 1956, **48**, 306–319). Radioactive mischmetal additions were made to a stainless steel containing 25% Ni, 20% Cr, 3·5% Cu and 2·5% Mo. The distribution of residual mischmetal constituents within the alloy were compared by autoradiography and metallographic analysis and showed that the Ce and Nd atoms were dispersed throughout the matrix and also slightly concentrated at the interdendritic zones of the as-cast material.—E. E. W.

High Temperature Oxidation of Nickel-Chrome Alloys. J. Moreau. (*Corrosion et Anticorrosion*, 1956, **4**, June, 211–216). To assist in resolving what happens during high temperature oxidation of binary alloys, whose constituents have different affinities for oxygen, a range of nickel-chrome alloys is oxidized under atmospheric pressure at 900°–1300° C. X-Ray diffraction and micrographic results enable a common reaction mechanism to be proposed.—T. E. D.

Carbide Precipitation in Tungsten–Chromium Steels below 700° C. K. Kuo. (*J. Iron Steel Inst.*, 1957, **185**, Mar., 297–303.) [This issue].

Heat- and Corrosion-resisting Sintered Materials. (2. *Plansee Seminar "de Re Metallica"* 1955). **Structural Investigations of W-Cr and Mo–Cr-rich Alloys of the Systems W–Cr–Ni and Mo–Cr–Fe.** H. Bückle. (223–238). **Electron Microscopy of Hard Alloy Structures.** R. Bernard. (41–49). Tungsten carbide-cobalt is examined. **The Stability of Some Melted Silicides of Potential Value in High Temperature Materials.** D. A. Robins and I. Jenkins. (187–198). **Molybdenum disilicide as High-temperature Material.** E. Fitzer. (56–79). The course of oxidation is studied. **The Formation of Silicides.** H. Nowotny, H. Kudielka and E. Parthé. (166–173). Ternary diagrams are given. **The Systems Niobium-Silicon and Vanadium-Silicon.** R. Kieffer, H. Schmid and F. Benesovsky. (154–165).

A New "Kurnakov" Compound Fe_3V in the Fe–V System. I. J. Kornilov and V. S. Mikheev. (*Doklady Akad. Nauk SSSR*, 1955, **104**, (1), 88–90). The compound was prepared from a solid solution by heating at 1220° for 20 h and 1320° for 2 h, quenching and annealing at 900° for 70 h. Hardness shows a minimum at 25 atomic % V and the conductivity and its temperature coefficient show maxima.

CORROSION

The Corrosion of Cast Iron. R. I. Higgins. (*Brit. C.I. Res. Assoc. J. Res. Dev.*, 1956, **6**, Feb., 165–177). The behaviour and suitability of different types of cast iron in various conditions and media of corrosion are discussed. Unalloyed, low alloy, and high alloy cast iron (including austenitic, high-silicon, high-chromium irons) are considered. Data is given on the influence of type of material and on the behaviour of different cast irons under varying conditions of acid and alkaline environment. Corrosion in salt solutions, natural and industrial waters, atmospheres and soil are also considered.

Report of Committee A-5 on Corrosion of Iron and Steel.

(*Amer. Soc. Test. Mat. Preprint No.* 3, 1956). Results of cumulative atmospheric corrosion tests obtained during 1955 are given together with a draft specification for galvanized poultry netting.—B. G. B.

Report of Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys. (*Amer. Soc. Test. Mat. Preprint No.* 6, 1956). Results are given of cumulative corrosion tests obtained during 1955 on nickel bearing and non-nickel bearing stainless steels.—B. G. B.

Chemical and Electrochemical Corrosion. H. Grubitsch. (*Z. Metallkunde*, 1956, **47,** Mar., 184–190). After giving the various definitions of electrochemical and corrosion phenomena, the author points out the difficulties of the local cell theory and gives evidence in support of the topochemical adsorption theory. It is shown that adsorption according to Van der Waals is not inconsistent with the electrochemical corrosion theory. Rate of corrosion is determined by processes of diffusion and adsorption and phase boundary reactions. Immersion in an aqueous medium also produces purely chemical reactions. (104 references).—L. D. H.

Report of Task Group on Inspection of Corrosion-Resistant Steels in Architectural and Structural Applications. J. B. Henry, Jun. (*Amer. Soc. Test. Mat. Proceedings*, 1955, **55,** (160–168). Recommendations of types of steel for different locations and design features are appended.

Effect of a Rolled or Heat-Treated Surface on the Corrosion of Steel and the Life of Protective Coatings. F. Eisenstecken. (*Arch. Eisenhüttenwesen*, 1956, **27,** Mar., 179–185). The author describes investigations of the effect of a scale film on the corrosion of a standard structural steel in aqueous solution, in situations exposed to weather, and in boiler parts. The effect of the scale film in the presence of protective paint is also discussed.

Influence of the Structure of Mild Steels on Their Brittleness Under Stress in Hydrogen Sulphide. E. Herzog. (*Compt. Rend.*, 1955, **241,** Oct. 24, 1129–1130). The time required for wire test-pieces of non-alloy or low-alloy mild steels strained near their elastic limits to break whilst in an hydrogen sulphide medium varies very widely according to the structure of these steels. The stable structures consist of sorbites, globular pearlites and lamellæ in a ferrite matrix. When the structure consists of an aggregate of pearlitic or bainitic carbides as well as ferrite rich in carbon, it gives a mechanically weak steel.

Electrical Grounding and Cathodic Protection at the Fairless Works. W. E. Coleman and H. G. Frostick. (*Trans. Amer. Inst. Elect. Eng., Part II, Applications and Industry*, 1955, **74,** 19–24). A steel grounding system has been introduced at the Fairless works of the U.S. Steel Corporation, all bare copper underground has been eliminated to reduce galvanic corrosion. Magnesium anodes protect the steel rods and partly protect underground piping, lead cables and foundations. Insulating coverings on pipes and cables reduce requirements for cathodic protection.—L. D. H.

Stress-Corrosion Cracking of Type 304 Austenitic Stainless Steel. H. L. Logan and R. J. Sherman, Jun. (*Welding J.*, 1956, **35,** Aug. 389s–395s). Forty solutions were investigated. A boiling 3½% NaCl-1% commercial NH_4NO_2 (pH 7·0) produced stress corrosion cracking in a few hours in 394 steel stressed to 80% or more and in 304 L steel stressed to 100% or more of their room temperature field strengths. No correlation was found between macroscopic strain and tendencies to develop stress-corrosion cracks. Pitting was generally produced by solutions having pH less than 4·0. Gas, believed to be hydrogen, was shown escaping from cracks.—U. E.

Report of Task Groups on Inspection of Nickel-bearing and Non-nickel-bearing Stainless Steels. C. P. Larrabee. (*Amer. Soc. Test. Mat. Proceedings*, 1955, **55,** 169–173). Exposures on 9 grades of steel are reported.

Electric Grounding Systems and Corrosion. L. P. Schaefer. (*Trans. Amer. Inst. Elect. Eng., Part II, Applications and Industry*, 1955, **74,** 75–80). A description is given of systems of earthing electrical currents, and the problems of underground corrosion are discussed.—L. D. H.

Corrosion Investigations Related to Adsorption Studies. C. C. Nathan. (*Corrosion*, 1956, **12,** Apr., 161t–168t). A variety of amines and organic acids have been studied in an attempt to relate their structures with their adsorption characteristics from benzene solution and with their effectiveness as inhibitors to the attack of acetic acid on iron powder. Strongly adsorbed molecules gave more protection than weakly adsorbed, easily desorbed ones. Primary amines proved to be better inhibitors than the corresponding secondary or tertiary amines. Considerable data on the adsorption characteristics of these compounds and of aromatic acids are given. The latter did not act as inhibitors.—J. F. S.

Potential-Building Phenomena in Austenitic Chrome-Nickel Steels Under Distilled Water and Under Neutral Halogen Salt Solutions. C. Carius. (*Arch. Eisenhüttenwesen*, 1956, **27,** May, 323–335). Potential measurements were made on three stainless austenitic chrome-nickel steels containing molybdenum up to 4·7%, immersed in the liquids named. Comprehensive results are given and discussed.

The Corrosion Properties of Chromium-Nickel-Manganese Austenitic Steels. W. G. Renshaw and R. A. Lula. (*Amer. Soc. Test. Mat. Preprint, No.* 81, 1956). The corrosion properties of the chromium-nickel-manganese steels, AISI 201 and 202, and also some lower carbon and higher chromium grades have been studied. The influence of the individual elements has been investigated, and the corrosion properties of the commercial analysis steels were evaluated in various corrosion media. The corrosion properties of sensitized material has been studied and in relation to this, the carbide and nitride precipitation.—B. G. B.

Mechanical and Metallurgical Factors Influencing the Wet Corrosion of Metals: Relation between Intergranular Corrosion and the Structure of Grain Boundaries. P. Lacombe. (*Mét-Corrosion-Indust.*, 1956, **31,** Sept., 337–354). Examples of the failure of metals and alloys due to intergranular corrosion are first given. The relation of the susceptibility to intergranular corrosion and grain boundary structure is then considered in detail. (50 references).—B. G. B.

Corrosion of Steam and Condenser Pipes, Causes and Prevention. J. Pierrey. (*Corrosion et Anticorrosion*, 1956, **4,** June, 225–230). Causes of corrosion and sources of oxygen and carbon dioxide are outlined. Methods of removing bicarbonates and carbonates are summarized and the method of injecting neutralizing chemicals into the steam is mentioned. The use of volatile amines injected into the boiler feed water is described and discussed. The use of "Film Forming" amines, namely long chain polar amines, is also examined.

Effect of pH and Velocity on Corrosion of Steel Water Pipes. R. Eliassen, C. Pereda, A. J. Romeo and R. T. Skrinde. (*J. Amer. Water Works Assoc.*, 1956, **48,** Aug., 1005–1018). The corrosion of steel pipes has been studied by the construction of a pipe network to simulate a water distribution system. The influence of pH and water velocity on the corrosion of test pipe sections in the absence of inhibitors has been investigated. (20 references).—B. G. B.

High Temperature Hydrogen Sulfide Corrosion in Thermofor Catalytic Reformers. E. B. Backensto, R. D. Drew, R. W. Manuel and J. W. Sjoberg. (*Corrosion*, 1956, **12,** May 235t–244t). Carbon and low chromium steels will not resist hydrogen sulphide corrosion under the high temperature conditions experienced in catalytic reformers for petroleum products. Corrosion tests using specimens inserted in various parts of two commercial plants confirmed laboratory experiments which indicated that only the 18 Cr–8 Ni and higher alloy stainless steels show good resistance to this type of corrosion. Calorized (diffused aluminium) coatings provided good protection to carbon steel specimens while hot-dipped aluminium was also effective except at the highest temperatures.—J. F. S.

Corrosion and Construction Problems of Sulphonic Acid Plant. G. C. Lowrison and F. Heppenstall. (*Chem. Process Eng.*, 1956, **37,** Oct., 339–345). Steel and iron alloys are referred to, and their corrosion resistance shown.

Corrosive and Erosive Effects of Acid Mine Waters on Metals and Alloys for Mine Pumping Equipment and Drainage Facilities. Anthracite Region of Pennsylvania. S. H. Ash, H. A. Dierks, E. W. Felegy, K. M. Huston, D. O. Kennedy, P. S. Miller and J. J. Rosella. (*U.S. Bur. Mines, Bull* 555, 1955, pp. 46). Tests on stainless steels and bronzes are described.

Nuclear Metallurgy. (*Amer. Inst. Min. Met. Eng. Special Report Series, No.* 2, 1956). Report of a Symposium, Feb. 20. **General Problems in the Application of Materials in Reactor Environments.** R. C. Dalzell. (1–4). An outline of conditions and classification of reactors. **The Behaviour of Materials in Aggressive Liquid Metals.** D. H. Gurinsky. (5–20). Methods of testing are described and the effect on steels of mercury with other metal additives, and of lead-bismuth and bismuth-uranium eutectics on stainless steels and other metals are

tabulated. Static and dynamic tests were used and the effect of bismuth on armco iron and other materials was determined and the solubility of iron and other metals in liquid Bi was measured. The reaction of dissolved Zn with iron was observed, and the course of precipitation of iron from bismuth. **Behaviour of Materials in Nonaggresive Liquid Metals.** E. G. Brush and R. F. Koenig. (21–32). Sodium and sodium-potassium alloys are discussed and the action on iron and other metals is discussed and tabulated, and photomicrographs are shown of the attack on stainless steels and other metals. Contained oxide or nitrogen attack the steels. **The Application of Materials in Low Temperature Water and Organic Liquid Cooled Reactors.** J. E. Draley and S. Greenberg. (33–53). Uranium and thorium and their alloys are discussed followed by a section on cladding materials, and then structural and control system materials are briefly considered, stainless steel is compared with aluminium alloys in this section. The discussion of insulators, moderators and shields follows. **Structural Materials for Use in the Pressurized Water Power Reactor.** D. M. Wroughton and D. J. De Paul. (55–69). A discussion of types of corrosion and release of corrosion products and their sources is followed by a section on radiation effects and then another on water analysis and conditions. Structural materials are tabulated including Armco 17-4 PH, carbon steels, and non-ferrous materials. **Corrosion of Materials in Fused Hydroxides.** G. P. Smith. (71–94). A large section on ceramics is followed by a section on metals including high-alloy irons. Mass transfer effects are considered and corrosion structures illustrated.

Atmospheric Exposure Tests of Wire and Wire Products. F. M. Reinhart. (*Amer. Soc. Test. Mat. Proceedings*, 1955, **55,** 124–148). Report of Subcommittee XV. Coated and stainless steel wires at 11 locations were exposed and inspected in successive years. Findings are tabulated.

Navy Experimental Work with Cathodic Protection. D. Gessow. (*Corrosion*, 1956, **12,** Mar., 100t–106t). The wide experience of the U.S. Navy of the operation, cost and usefulness of cathodic protection for the reserve and active fleet is reviewed. Cathodic protection of inactive ships is valuable. For active ships more experience is needed. The relative merits of using impressed currents with graphite or platinum-coated anodes and sacrificial anodes of magnesium, aluminium or zinc are discussed.—J. F. S.

Corrosion Reduction by Means of Inhibitors. M. Oudeman. (*Metalen*, 1956, **11,** July 31, 304–309). [In Dutch]. The paper discusses the effects of adding small amounts of inhibitors in anodic, cathodic and organic adsorbent form for reducing corrosion, particularly of steel. The application of inhibitors in various forms such as sodium hydroxide, carbonate and silicate, phosphates, chromates and nitrites is touched upon. Corrosion attributable to bacteria and condensates receives attention. (13 references).—F. R. H.

Rust-Ban. (*Esso Oilways*, 1956, **8,** (3), 19–21). The petroleum products marketed under this designation are described, and uses indicated.

ANALYSIS

A Non-Destructive Microchemical Method of Sorting Steels. W. R. Nall and R. Scholey. (*Metallurgia*, 1956, **54,** July, 97–102). A microchemical procedure is described for the rapid sorting of carbon and low alloy steels which uses simple inexpensive apparatus. The classification of unknown steels is based on the estimation of manganese, nickel, chromium and molybdenum and a small number of standard analysed steels are used for comparison purposes.—B. G. B.

Report of Committee E.3 on Chemical Analysis of Metals. (*Amer. Soc. Test. Mat. Preprint, No.* 57, 1956). A number of revisions to existing A.S.T.M. standard methods are proposed; these include the chemical analysis of steel, cast iron, open hearth iron and wrought iron. Details are given of a draft proposal for the chemical analysis of nickel-chrome and nickel-chromium-iron alloys.—B. G. B.

Chemical Analysis of Steel, Cast Iron, Open Hearth Iron and Wrought Iron. (*Amer. Soc. Test. Mat. Preprint No.* 57*a*, 1956). Details of a revised A.S.T.M. specification for the analysis of these irons is given in full.—B. G. B.

Mixed Perchloric-Phosphoric Acids as Solvents for Iron Ores. C. A. Goetz and E. P. Wadsworth, Jun. (*Analy. Chem.*, 1956, **28,** Mar., 375–376). The solutions can be passed through the Jones reductor and the iron titrated directly.

Hurry-up Solution Control. (*Steel*, 1956, **139,** July 30, 94–95). Charts for rapid analysis of pickle baths and nickel dip for porcelain enamelling are given.

Coulometric Titration of Iron, Cerium and Vanadium with Titanous Ion. J. J. Lingane and J. H. Kennedy. (*Anal. Chim. Acta*, 1956, **15,** Nov., 465–472).

Nitroresorcinol Monomethyl Ether as a Reagent for Iron and Cobalt. S. M. Peach. (*Analyst*, 1956, **81,** June, 371–373).

Tetraco-ordinated Complexes of Bivalent Metals and Thiourea. M. Nardelli, L. Cavalca and A. Braibanti. (*Gazz. Chim. Ital.*, 1956, **86,** Oct., 867–877). Ferrous complexes are described.

Determination of Small Amounts of Carbon in Steel by Low-pressure Analysis. R. M. Cook and G. E. Speight. (*Analyst*, 1956, **81,** Mar., 144–152).

The Determination of Low Carbon Contents in Steel by Multiple Factor Weight Combustion. B. Bagshawe and R. H. Pinder. (*Analyst*, 1956, **81,** Mar., 153–159).

Tests to determine Carbon and Sulphur in a Combustion Furnace with High-Frequency Heating. B. Elgh, G. Ericson and A. Wiman. (*Jernkontorets Ann.*, 1956, 140, 5, 373–385). [In Swedish]. Detailed tests were made on a high-frequency furnace to determine its advantages, as compared with a resistance furnace, in the determination of carbon and sulphur in steel. Results are given of 30 series of tests. The elements can be determined in 3 minutes, and the method can be used for carbon and alloy steels, ferro-alloys, cast iron and certain non-ferrous alloys.—G. G. K.

Rapid Method for the Determination of Phosphorus. U. Fernlund, S. Zechner and R. Olofsson. (*Jernkontorets Ann.*, 1956, **140,** (5), 386–388). [In Swedish]. Adapted for use with North Swedish iron ore, a modification of the quinoline molybdate method enables an analysis for phosphorus to be completed within $3\frac{1}{2}$ minutes. The sample is dissolved in HCl mixed with $KClO_3$ solution and hot water, precipitated with quinoline molybdate solution, filtered, and then titrated with standard acid and alkali solutions.—G. G. K.

Determination of Hydrogen in Arc Furnace Steels. W. Geller, K. Bungardt, and P. Hammerschmid. (*Arch. Eisenhüttenwesen*, 1956, **27,** Apr., 235–240). The present state of knowledge is reviewed. The determination of diffusible hydrogen at 600° C, and the determination of residual hydrogen, are described. The behaviour of hydrogen during the manufacture of steel in basic electric arc furnaces, and the effect of hydrogen content on flocculation, are discussed.

Determination of Micro Quantities of Hydrogen, Combustion-Manometric Method. B. D. Holt. (*Analy. Chem.*, 1956, **28,** July, 1153–1157). The method was developed for metallic uranium. Carbon could be determined also if required.

Determination of Aluminium in Iron and Steel with the Aid of Chromatographic Separation. J. R. Bishop. (*Analyst*, 1956, **81,** May, 291–294).

Photometric Determination of Small Amounts of Chromium in Steel. A. Zastera. (*Draht. German Ed.*, 1956, **7,** May, 184–185). As any considerable amount of chromium is disadvantageous in wire drawing, a rapid method of determining chromium contents between 0·01–0·15% is required. A method using diphenylcarbazide is described.

Colorimetric Determination of Chromium in Steels. H. Carrancio de la Plaza. (*Inst. Hierro Acero*, 1956, **9,** Apr., 472–477. Special Number). [In Spanish]. The colorimetric determination of chromium is discussed, and it is concluded that (*a*) the best calibration curve is obtained by using measured volumes of potassium dichromate added to pure iron solutions, (*b*) neither the presence of iron nor elapsed time influences the colour, (*c*) the optimium quantity of sodium nitrite is 2 drops per cell, and (*d*) the best reproducibility is for chromium contents between 0·6 and 9%. The diphenylcarbazide method is also discussed, and a slight modification, intended to shorten the assay, is given.—P. S.

Recommended Methods for the Analysis of Trade Effluents. Methods of Determination of Chromium, Lead and Selenium. Joint A.B.C.M.-S.A.C. Committee. (*Analyst*, 1956, **81,** Oct., 607–614).

Simultaneous Microdetermination of Copper and Iron Using Mixed Phenanthrolines. B. Zak and N. Ressler. (*Analy. Chem.*, 1956, **28,** July, 1158–1161).

3-Hydroxy-1 : 3-diphenyltriazine as a Reagent for Copper (II), Palladium (II), and Nickel (II) and 3-Hydroxy-1-*p*-chlorophenyl-3-phenyltriazine for Titanium (IV). N. C. Sogani and S. C. Bhattacharyya. (*Analy. Chem.*, 1956, **28,** Oct., 1616–

1618). Iron interferes with Ti determination, but not with Cu, Ni or Pd.

Determination of Small Quantities of Nickel with α-Furildioxime. C. G. Taylor. (*Analyst*, 1956, **81**, June, 369–370).

Analysis of Nickel in Plating Baths. F. Brako. (*Metal Finishing*, 1956, **54**, Sept., 61–64). The sodium cyanide-murexide method is described.

A New Method for the Potentiometric Determination of Tungsten in Steelmaking. R. Suarez Acosta. (*Inst. Hierro Acero*, 1956, **9**, May, 586–594. Special Number). [In Spanish] The solution is reduced by zinc and finally 0·1 N chromous sulphate after which the tungsten is evaluated by oxidation with previously standardized potassium dichromate solution. The presence of molybdenum and titanium influence the potential curves but not the accuracy of the determination. Details of the method, which is speedy and reliable, are given.

New Analytical Methods and Their Significance in Control Process in Steelmaking. T. Chlebovsky. (*Hutnik*, 1956, **6**, (6), 162–167). [In Czech]. Applications and scope of spectrum analysis, polarometric analysis, potentiometric titrations and other analytical methods in the works laboratory are reviewed.

Spectrophotometric Determination of Aluminium in Ferrous and Non-ferrous Alloys. R. J. Hynek and L. J. Wrangell. (*Analy. Chem.*, 1956, **28**, Sept., 25, 1520–1527). Application of 8-hydroxyquinaldine is described.

Analysis by Infra-Red Absorption and its Application to the Determination of Carbon Monoxide. K. Luft. (*Rev. Tech. Luxembourg*, 1956, **48**, Apr.-June, 75–80). A description is given of the principle of the infra-red gas analyser and in particular its application to the determination of carbon monoxide. The use of such equipment is described.—B. G. B.

The Direct Reading Spectrograph: An Application to a Chemical Laboratory. (*J. d'int. tech. Indust. Fonderie*, 1956, July, 21–27). The principle of the technique is first explained. The use of this, together with calorimetric and polarographic methods account for 70% of the 16,000 to 17,000 analyses carried out in the Sèvres laboratory, which were previously carried out by classical wet methods.—B. G. B.

Microanalytical Investigations in Ferrous Research. II: Spectrochemical Investigation of the Separated Structural Constituents of Steels. W. Koch and S. Eckhard. (*Arch. Eisenhüttenwesen*, 1956, **27**, Mar., 165–176). Spectrochemical methods have very high sensitivity and can be used with quantities of 50μg. Accuracy is as good as that of other microanalytical techniques. Spectrographic analysis cannot be extended to carbon, nitrogen, sulphur and phosphorus, which require other microanalytical methods. The time required for spectrochemical examination is materially less than with other procedures.

The Application of Radioactive Methods to Metallographic Problems (Autoradiography). G. Glawitsch. (*Z. Metallkunde*, 1956, **47**, Mar., 199–202). Spreading of the area of blackening in autoradiography results in a reduction of resolving power; this can be counteracted by the use of the transfer printing method. A non-ferrous application of the technique is given.

Mixing of the 'Analysis' Sample of Coal or Coke. J. E. Barker, R. A. Mott and W. C. Thomas. (*Fuel*, 1956, **35**, Oct., 493–500). The superiority of a laboratory mixer designed by the British Coke Research Association over the U.S. Bureau of Mines mixing wheel and the " Quickmix " is demonstrated. Critical factors in the design of the mixer are described and the importance of efficient mixing is shown.—B. G. B.

INDUSTRIAL USES AND APPLICATIONS

Symposium on the Application of Low-Alloy Steels for Welded Pressure Vessels. (*West Scotland Iron Steel Inst.*, 1956, Oct. 19). **Some Principles of Design for Pressure Vessels and Boilers Made of Low-Alloy Steel.** W. P. Kerkhof. (Paper No. 490, 16 pp.). The author discusses whether the conventional methods of stress calculation should be replaced by more modern and more accurate methods. In the course of the article the author examines various factors: maximum stress and range of stress; ultimate tensile strength, yield point and fatigue; the influence of the contents of the vessel; and the influence of the weld. A new and simple method of calculation is explained and it is claimed that this new method will result in more economical use of material. **The Welding of Large Pressure Vessels in Low-Alloy Steels.** H. Harris. (Paper No. 491, 26 pp.). The author points out that the constant increase in both pressures and temperatures has resulted in pressure vessels that have reached the practical limit of thickness in mild steel and that, consequently, low-alloy steels with high tensile properties must now be adopted. The needs of the fabricator are then considered and the suitability of a particular high-tensile low-alloy steel (C 0·17, Si 0·30, Mn 1·40, Cr 0·70, Mo 0·28, V 0·10, S 0·05, P 0·05%) is assessed. It is shown also that steel has advantages for thinner vessels, especially in the quenched and tempered condition. **A Low-Alloy Quenched and Tempered Steel for Pressure Vessels.** J. M. Hodge and L. C. Bibber. (Paper No. 492, 41 pp.). The author summarizes the advantages of using a material of higher strength than carbon steel and illustrates these advantages by presenting the mechanical properties of " T-1 " steel for which a typical analysis is given. Results are also given of a comprehensive test programme on welded pressure vessels of this steel. A number of tables, diagrams and graphs are included. (10 references). **Development of a Manganese-Chromium Molybdenum-Vanadium High-Tensile Weldable Steel for Pressure Vessels.** W. Barr and I. M. MacKenzie. (Paper No. 493, 24 pp.). The general characteristics of a low-carbon low-alloy semi-air-hardening steel are discussed and steps in the development of the steel are described. This steel is the latest addition to the " Ducol " series developed by the authors and is known as " Ducol W. 30." The mechanical properties, response to heat-treatment and weldability of the steel are examined. A number of tables and graphs are included. **Properties of Molybdenum-Boron High Tensile Steels.** L. Reeve. (Paper No. 494, 14 pp.). The author gives details of a high-tensile, high-yield point, low-carbon steel containing molybdenum (0·40–0·55%) and boron (0·0013–0·0035%). The steel, known as " Fortiweld," has good creep and rupture characteristics and excellent weldability. The mechanical properties of the material in the as-rolled condition and after various heat-treatments are presented and discussed. The author concludes by considering the various applications of the steel. **Important Considerations for the Welding of Chromium-Molybdenum Steels.** O. R. Carpenter and C. Floyd. (Paper No. 495, 33 pp.). The most important practical considerations for the welding of the common chromium-molybdenum steels are discussed. The development of a family of low-carbon electrodes, containing 1–5% Cr, 0·5 or 1·0% Mo and a maximum carbon content of 0·05%, is described and the metallurgical advantages demonstrated. Data on the room- and elevated-temperature mechanical properties of the weld metals are given. High temperature stress-rupture data on the weld metals are also presented and compared with equivalent wrought materials.—L. E. W.

Tentative Standard Specifications for Dimensions for Steel Water Pipe Fittings. (*J. Amer. Water Works Assoc.*, 1956, **48**, July, 889–900). A proposed standard specification for American steel water pipe fittings is given.—B. G. B.

High Pressure Tubing. W. Paul and D. M. Warschauer. (*Rev. Sci. Instruments*, 1956, **27**, June, 418–419). Stainless steel tubing $\frac{1}{8}$ in. o.d. by 0·025 in. i.d. has been found to withstand 20,000 atmos. Connecting plugs are shown for these pressures.

An Appraisal of the Properties and Methods of Production of Laminated or Composite Ship Steel Plate. (*Special Rept. Serial No. SSC-84 submitted to the Ship Structure Committee, Division of Engineering and Industrial Research, National Academy of Sciences—National Research Council*, Washington, 1956, pp. 60). The object of the work was principally to minimize brittle fractures by the use of layers or inserted rods of notch tough materials. Discussion of possible solutions for the problem is followed by the conclusions that the processes named are unlikely to be effective and that work should be discontinued. **The Effect of Variations in Texture on Energy Absorption and Transition Temperature.** G. A. Mangis and F. W. Boulger (pp. A1–A32). The questions of plates containing layers of weakness or of notch-tough materials are discussed and measurements are tabulated and microstructures shown. It is concluded that the former suggestion is not likely to be beneficial but that cladding or the incorporation of tough rods should produce increased resistance to brittle fracture. **Suggestions for the Development of Texturally Tough Low Carbon Steels.** E. Orowan. (pp. B1–B6). An account of research on the above topics at the Battelle Institute. **Keyhole Charpy Impact Data on Equipment Steels.** (pp. C1–C4). The Report concludes with discussions by E. Orowan and a reply by the Chairman, P. E. Kyle. Some divergence in aims is disclosed.

Report of Committee B-1 on Wires for Electrical Conductors. (*Amer. Soc. Test. Mat. Preprint No.* 7, 1956). A number of standard specifications for electrical conductors, including copper covered steel conductors, are reviewed.—B. G. B.

Orientated Steel and Today's Turbine Generators. G. W. Staats. (*Blast Furn. Steel Plant*, 1956, **44,** Aug., 940–944). Examples are cited which show how the efficiency of transformers and generators has been improved by the production of grain orientated iron-silicon alloys obtained by cold rolling.

The Choice of Materials for Airframes. K. L. C. Legg. (*Aircraft Eng.*, 1956, **28,** Sept., 304–312). Properties required are discussed and steels are evaluated among many other possible materials.

MISCELLANEOUS

The Reduction of Ore to Metal. L. M. Pidgeon. (*Metal Progress*, 1956, **70,** Aug., 81–85). A short review of various methods of reducing metal compounds to metals is given. The use of magnesium and calcium to displace other metals is discussed.—B. G. B.

On the Kinetics of Reduction of Silicon. O. A. Esin and V. N. Shikhov. (*Ivest. Akad. Nauk SSSR, Otdelenie Tekn. Nauk*, 1956, (6), 113–118). [In Russian]. Kinetics of the reduction of silicon from silica-saturated slags by iron were investigated. It was established that the velocity of reduction greatly decreases when magnesium oxide in slag is replaced by calcium or barium oxide. An increase in temperature considerably increases the velocity of reduction of silicon from barium slags. The replacement of barium oxide by calcium or magnesium oxides strongly decreases the influence of temperature. It is assumed that the influence of cations on the velocity of the process is due to differences in the degree of weakening of the strength of silicon-oxygen bonds in slag.—V. G.

Effect of Proton Irradiation upon the Rate of Solution of Fe_2O_3 in Hydrochloric Acid. M. Simnad and R. Smoluchowski. (*J. Chem. Phys.*, 1955, **23,** Oct., 1961–1962). The rate is significantly increased.

Structural Study of Iron Selenides $FeSe_x$. I. Ordered Arrangement of Defects of Fe Atoms. A. Okazaki and K. Hirakawa. (*J. Phys. Soc. Japan*, 1956, **11,** Sept., 930–936).

On the Reaction in Melts between Calcium Sulphate and Ferrous Sulphide. E. J. Kohlmeyer and G. Lohrke. (*Z. Erz. u. Met.*, 1956, **9,** July, 326–331).

The First Commercial Plant for Electrowinning of Chromium. M. C. Carosella and J. D. Mettler. (*Metal Progress*, 1956, **69,** June, 51–56). A description is given of a new plant at Marietta, Ohio, for the production of 99·8% pure chromium and of pilot plant studies. The raw material is high carbon ferrochromium produced in an electric furnace. This is dissolved and the chromium electrodeposited in diaphragm cells from a chrome alum solution. The plant is designed to produce 2000 tons of chromium per year.—B. G. B.

The Reclamation of Tin from Soldered Metal Scrap. W. M. Halliday. (*Sheet Metal Ind.*, 1955, **32,** July, 505–506, 508). A brief survey of some methods of reclaiming tin is given, and the "Lead-Wash" Recovery Process is described. Soldered and tinned scrap parts are immersed in molten lead, and tin is isolated by skimming the oxide which is then reduced with fine coal dross.—A. H. M.

Zirconium. S. M. Shelton. (*U.S. Bur. Mines Bull.* 561, 1956, pp. 180). Ores, production, properties and fabrication are described, and alloys and alloy systems including Zr–Fe are described followed by sections on uses, cost and analysis.

BOOK NOTICES

BRETON, H. LE. "*Défauts des Pièces de Fonderie.*" Tome I. "*Défauts dus au mode de Solidification de l'Alliage Coulée.*" La. 8vo, pp. 284. Illustrated. Paris, 1956: Editions Eyrolles. (Price 3045 fr.).

This is a textbook that seeks to deal with those foundry defects which may be attributed to the way in which metal solidifies. The method of presentation is simple and logical, but inadequate and, at times, inaccurate. Each type of defect is discussed generically and its cause and mechanism of formation are explained. The practical occurrence of the defect is described and the means by which it may be reduced or eliminated are summarized.

In the first Part a brief and very much simplified account is given of the origins of shrinkage and the main types of metal constitution. Liquid shrinkage is briefly dealt with. The chapter on defects due to combined liquid and solid contraction deals with porosity and cavity formation, the occurrence of hot spots and the design and use of feeders and chills. Principles of feeding are discussed.

Cracks, tears and residual stresses are described under the classification of solid contraction. They are considered mainly from the standpoint of thermal and design factors. A chapter is devoted to casting design, and this subject receives emphasis throughout the book.

The second Part starts with a note on the metallography of solidifying metals; brief chapters then follow on grain size, segregation, mis-running, cold shuts and surface folds.

The book is liberally illustrated with sketches and diagrams. Use is made of symbols to indicate temperatures, volumes, etc., but no formulæ involving more than the simplest conceptions are given. There are no references and no detailed index.

The weakness lies in over-simplification. Although the founder may have his ideas on design factors clarified, he will usually find his particular problem inadequately dealt with. For example, the book avoids the deeper waters of the feeding range of risers, centre-line porosity in flat castings and recent hot-tearing theory. Little indication is given of the effects to be expected from variations in metal composition.

The student will find detailed simple explanations of the mechanisms of defect formation without reference to other published, often controversial, work. There is over-simplification of subjects such as segregation, and the explanations given of the inverse segregation of phosphorus and of inverse chill in cast iron would be unacceptable to some authorities. Furthermore, some of the gating systems illustrated are based upon misconceptions according to modern views on gating practice.

To be of maximum value a work of this kind should be authoritative and reasonably complete. This book does not cover its subject adequately and many will disagree with some of its views.—I. C. H. HUGHES.

BARWELL, F. T. "*Lubrication of Bearings.*" 8vo, pp. xii + 292. Illustrated. London, 1956: Butterworths Scientific Publications. (Price 50*s.*).

Dr. Barwell has brought together in this book a lot of information about the theory and performance of journal bearings. The book is not a mathematical treatise on hydrodynamic lubrication. Mathematics are used, as indeed they must be, but the author's idea was clearly to show the significance of the mathematical relationships and how they could be applied to bearing design. This he has done by making use of relationships which have experimental support.

The author outlines a simple procedure for the bearing designer to follow. He shows how, for example, the bearing dimensions may be easily determined from a knowledge of load, speed, oil viscosity and shaft diameter. Although there may be limitations to applying the results of such calculations directly to the design of bearings, the procedure should enable the designer to make useful comparisons with the known performance of other bearings within his experience.

The book deals primarily with journal bearings, but thrust bearings, slider bearings and hydrostatic bearings are also discussed. There is a section dealing with the lubrication of bearings by grease (rheodynamic lubrication).

The author also describes how heavily loaded bearing surfaces, as in gears, are lubricated by hydrodynamic films. The information given is right up-to-date, and includes a short account of the benefits to be derived from "elasto-hydrodynamic effects."

A chapter is devoted to materials for bearings. Dr. Barwell discusses the requirements of these materials, such as conformability, resistance to corrosion, ability to slide against a steel shaft without seizure, embedability, and so on, from the designers' point of view.

To complete the subject matter of the book, the author reviews the various types of lubrication, the fundamentals of friction and wear, and methods of testing bearings.

He has dealt with the subject matter in a concise manner, and, although there is so much information in the book, it is a compact volume and makes a valuable reference work for the bearing designer and research worker. The book is enjoyable to read, the text and diagrams being particularly well arranged.—T. B. LANE.

TEGART, W. J. MCG. "*The Electrolytic and Chemical Polishing of Metals in Research and Industry.*" 8vo, pp. x + 129. Illustrated. London, 1956: Pergamon Press, Ltd. (Price 30*s.*).

In recent years considerable interest has been aroused in both scientific and industrial circles in electrochemical and chemical processes resulting in the production of a polished appearance on metal surfaces. From the scientific standpoint, the interest is not merely academic, since electrolytic polishing has been developed into a most valuable technique for the preparation of metal surfaces for metallographic examination. Industrially, the economic advantages of substituting for expensive mechanical methods of polishing electrochemical or, better still, chemical methods have again made the perfection of such processes a most desirable objective.

The author of the present volume has succeeded in producing a very useful review of both of these fields of development in the remarkably small compass of just over 100 pages. He deals first with the theory devoting the opening three chapters to the mechanism of electropolishing, the electrical characteristics of the process and the factors influencing polishing conditions (30 pages). Thereafter he devotes about equal space, respectively, to the laboratory and research applications and the industrial applications of electro- and chemical polishing. In the laboratory applications, methods for polishing no fewer than twenty-six specific metals (apart from alloys) are described, while the industrial section deals with about a dozen of the common metals.

As might be expected the section on the laboratory methods and applications is the more authoritative, most of the "recipes" having been tried out and confirmed in the author's own laboratory (Division of Tribophysics, Melbourne, Australia).

There are one or two apparent contradictions in the text. Thus on page 76 it is asserted that "If a metal surface is electropolished prior to heavy electroplating, the bond obtained is much stronger than that with a mechanically polished surface, due to better continuity across the bulk metal/plated layer interface." Lower down, this is countered by the statement ". . . electropolished metals often have a passive film on the surface after treatment, and this film can reduce adhesion considerably." It is of course a fact that where "heavy" electrodeposits are applied in industrial practice, the basis metal is invariably etched to provide optimum adhesion of the deposit.

A very useful selection of industrial processes is briefly but usually adequately presented. There is, however, a surprising omission of what is perhaps the most important of all these processes, namely, that connected with the treatment of high-purity aluminium alloys. This process has made such headway (particularly on the Continent) that it has replaced chromium plating as a finish on certain components e.g. in the motor car accessory field.

The book is well written and undoubtedly a welcome addition to the somewhat scattered literature which is to be found on the subject, its principal virtue being its combination of comprehensiveness with compactness.

S. WERNICK.

NEW PUBLICATIONS

AMERICAN WELDING SOCIETY. "*Resistance Welding, Theory and Uses.*" Prepared by the Resistance Welding Committee, American Welding Society. 8vo, pp. ix + 163. Illustrated. London, 1956: Chapman and Hall, Ltd. (Price 36*s.*).

BOICHENKO, M. S., V. S. RUTES and N. A. NIKOLAEV. "*Continuous Casting of Steel.*" [In Russian]. (Academy of Science U.S.S.R. Popular Science Series). 8vo, pp. 52. Illustrated. Moscow, 1956: Publishers of the Academy of Science U.S.S.R.

BELCHER, W. E., junr., DONALD ROBERTSON and W. F. HICKS. "*Temperature Measurement.*" A series of three Educational lectures on Temperature Measurement presented to members of the ASM during the thirty-sixth National Metal Congress and Exposition, Chicago, October 1 to 5, 1954. 8vo, pp. [iv +] 75. Illustrated. Cleveland, Ohio, 1956: American Society for Metals.

COUNCIL OF IRONFOUNDRY ASSOCIATIONS. "*A Practical Guide to the Design of Grey Iron Castings for Engineering Purposes.*" [Translated from a French Report bearing the same title published in 1954 by the] Commission Technique de la Métallurgie des Fontes du Centre Technique des Industries de la Fonderie. La. 4to, pp. 55. Illustrated. London, 1956: The Council.

CRUCIBLE STEEL COMPANY OF AMERICA. "*Heat Treatment and Pickling of Crucible Registal Stainless Steel.*" 8vo, pp. 16. Illustrated. Pittsburgh [1956]. The Company.

"*A History of Technology.*" La. 8vo, illustrated. Volume I. "*From Early Times to Fall of Ancient Empires,*" edited by Charles Singer, E. J. Holmyard and A. R. Hall, assisted by E. Jaffé, R. H. G. Thomson and J. M. Donaldson. Volume II. "*The Mediterranean Civilization and the Middle Ages, c. 700 B.C. to c. A.D. 1500,*" edited by Charles Singer, E. J. Holmyard, A. R. Hall and Trevor J. Williams, assisted by E. Jaffé, Nan Clow and R. H. G. Thomson. Oxford, 1956: Clarendon Press. (Price 168*s.* each volume).

"*Kempe's Engineers Year Book 1957.*" 62nd edition. Edited by C. E. Prockter under the direction of B. W. Pendred. 2 vols., 8vo. Illustrated. Volume One, pp. xiv + 1324; Volume Two, pp. x + 1416. London, 1957: Morgan Brothers (Publishers), Ltd. (Price 82*s.* 6*d.*, the two volumes in case).

KLAS, HEINRICH and HEINRICH STEINRATH. "*Die Korrosion des Eisens und ihre Verhütung.*" (Stahleisen-Bücher, Band 13). 8vo, pp. xii + 504. Illustrated. Düsseldorf, 1956: Verlag Stahleisen m.b.H. (Price DM. 55.—).

NOTT-BOWER, SIR GUY, and R. H. WALKERDINE (Editors). "*National Coal Board. The First Ten Years.*" 4to, pp. 118. Illustrated. London, 1956: The Colliery Guardian Co. Ltd. (Price 21*s.*).

SKAKOW, A. I. "*The Quality of Steel Rails.*" 8vo, pp. 367. Illustrated. Moscow, 1955: State Scientific-Technical Publishers of Literature on Ferrous and Non-Ferrous Metals.

STAUDINGER, HEINRICH. "*Das Schleifen und Polieren der Metalle.*" 5th Edition. pp. 64. Illustrated. Berlin, Göttingen and Heidelberg, 1955: Springer-Verlag. (Price DM. 3·60).

VEREIN DEUTSCHER EISENHÜTTENLEUTE. "*Stahleisen-Kalender* 1957." Sma. 8vo, pp. 321. Illustrated. Düsseldorf, 1956: Verlag Stahleisen.

VEREIN DEUTSCHER EISENHÜTTENLEUTE. "*Stahldrahterzeugnisse.*" Herausgegeben vom Ausschuss für Drahtverarbeitung im Verein Deutscher Eisenhüttenleute. 8vo. Illustrated. Band I, pp. xii + 340. Band II, pp. x + 315. Düsseldorf, 1956: Verlag Stahleisen m.b.H.

WEVER, FRANZ and ALFRED KRISCH. "*Metallkundliche Untersuchungen am Zeitstandproben.*" (Forschungsberichte des Wirtschafts—und Verkehrsministeriums Nordrhein-Westfalen. Nr. 315). Folio, pp. 25. Illustrated. Köln and Opladen, 1956: Westdeutschen Verlag. (Price DM. 9.15).

WEVER, FRANZ, ALFRED KRISCH and HANS-JOACHIM WIESTER. "*Veränderung in Gefügeaufbau von Chrom–Nickel–Molybdän–Stählen bei langzeitiger Beanspruchung im Zeitstandversuch bei* 500°." (Forschungsberichte des Wirtschafts- und Verkehrsministeriums Nordrhein-Westfalen. Nr. 314). Folio, pp. 35. Illustrated. Köln and Opladen, 1956: Westdeutscher Verlag. (Price DM. 11.70).

WEVER, FRANZ and WERNER LUEG. "*Warmstauchversuche zur Ermittlung der Formänderungsfestigkeit von Gesenkschmiede-Stählen.*" (Forschungsberichte des Wirtschafts- und Verkehrsministeriums Nordrhein-Westfalen. Nr. 283). Folio, pp. 31. Illustrated. Köln and Opladen, 1956: Westdeutscher Verlag. (Price DM. 9.90).

HENRY WIGGIN & Co., LTD. "*The Nimonic Alloys, Design Data.*" 4th Edition. La 8vo, pp. 54. Illustrated. Birmingham, 1956: The Company.